# NUTRIENT MANAGEMENT STRATEGIES FOR NECTARINE ORCHARDS

**By**

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# DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree.

Signature

Date

**Summary**

The macro-element uptake and distribution by higher density central leader 'Donnarine' nectarine trees was studied through the sequential excavation of trees. A large portion, 41.5%, of the nitrogen manifested in the new growth from dormancy up to pit-hardening, originated from nitrogen reserves in the permanent structure. The permanent structure was also an important source of phosphorous reserves. Of the phosphorous in the fruit, leaves and new shoots at pit-hardening, 35.0% came from reserves in the permanent structure. Potassium did not act as an important reserve in the nectarine trees and was taken up throughout the season. From pit hardening to harvest the fruit represented the most important sink for potassium. Calcium and magnesium, like potassium, did not play significant roles as reserves in the nectarine tree and must be available for uptake from the beginning of the season for new growth and development as well as fruit quality.

The micro-element uptake and distribution was also studied through the sequential excavation of the same 'Donnarine' nectarine trees. Little scientific data is available on this topic. Manganese and iron was found to act as important reserves in the tree with 46.2% of manganese and 59.5% of the iron found in the new growth at pit-hardening coming from reserves translocated from the permanent structure. Zinc and boron reserves also play a role in nectarine trees, but to a lesser extent than manganese and iron.

The seasonal mineral nutrient demand of the same 'Donnarine' nectarine trees was determined through the sequential excavation of trees and losses and fixation was calculated. Guidelines regarding nutritional requirements per ton of fruit produced per hectare by higher density nectarine orchards are respectively 3.82kg nitrogen, 0.35kg phosphorous, 4.43kg potassium, 1.53kg calcium, 0.52kg magnesium, 32.45g sodium, 9.44g manganese, 37.46g iron, 3.24g copper, 13.95g zinc and 10.52g boron. Sodium is not commonly considered to be essential to higher plants, but was included in the trial.

Nutrient solutions with four different EC (electrical conductivity) levels were applied to 'Donnarine' nectarine trees under pulsating drip fertigation for three periods of

different lengths, before harvest. Raising the nutrient solution EC to positively affect fruit quality is a technique widely utilised in the vegetable industry. This technique did, however, not have similar positive effects on nectarine fruit grown under a pulsating drip fertigation system. Good production practices such as accurate nutrition and irrigation as well as the correct horticultural inputs should be the primary focus of producers who wish to alter or improve the fruit quality of their crop.

**Opsomming: Voedingbestuur strategieë in nektarien boorde**

Die makro-element opname en verspreiding deur hoër digtheid sentrale leier ‘Donnarine’ nektarien bome is bestudeer d.m.v. opeenvolgende opgrawings van volledige bome en die ontleding van monsters. ‘n Groot hoeveelheid, 41.5%, van die stikstof wat tydens pitverharding in die nuwe groei teenwoordig was, is d.m.v. translokasie vanuit die permanente struktuur van die boom afkomstig. Die permanente struktuur was ook ‘n belangrike bron van fosfaat reserwes. Teen pitverharding was 35.0% van die fosfaat in die nuwe groei afkomstig vanuit die permanente struktuur. Bevindings het getoon dat kalium nie as ‘n reserwe in die nektarien bome opgetree het nie en dié element is deur die groeiseisoen opgeneem. Vanaf pitverharding tot en met oestyd was die vrugte die sterkste setel van aanvraag vir kalium. Kalsium en magnesium het, soos in die geval van kalium, nie ‘n belangrike rol as reserwe vertolk nie. Beskikbaarheid van hierdie elemente vir opname vanaf die begin van die groeiseisoen is dus baie belangrik vir nuwe groei en ontwikkeling asook vrugkwaliteit.

Die mikro-element opname en distribusie van dieselfde ‘Donnarine’ nektarien bome is ook bestudeer d.m.v. opeenvolgende opgrawings en analise van volledige bome. Min wetenskaplike literatuur oor hierdie onderwerp is beskikbaar. Bevindings het getoon dat mangaan asook yster baie belangrike reserwes in die nektarien boom is. Tydens pitverharding was 46.2% van die mangaan en 59.5% van die yster wat in die nuwe groei teenwoordig was, afkomstig vanaf reserwes uit die permanente struktuur van die boom. Verder het sink en boor ook as reserwes opgetree, maar tot ‘n mindere mate as mangaan en yster.

Die seisoenale behoeftes aan minerale voeding van dieselfde ‘Donnarine’ nektarien bome is bepaal d.m.v. opeenvolgende opgrawings en analise van volledige bome asook die bepaling van verwyderingsverliese en vaslegging. Voedingsriglyne is vasgestel i.t.v. die hoeveelheid voedingstof wat per hektaar benodig word om een ton nektariens te produseer. Die riglyne is as volg: 3.82kg stikstof, 0.35kg fosfaat, 4.43kg kalium, 1.53kg kalsium, 0.52kg magnesium, 32.45g natrium, 9.44g mangaan, 37.46g yster, 3.24g koper, 13.95g sink en 10.52g boor. Natrium word nie in die algemeen as ‘n essensiële plantvoedingselement beskou nie, maar is by die berekeninge ingesluit.

Voedingsoplossing met vier verskillende vlakke van EG (elektriese geleiding) is vir drie periodes van verskillende lengtes aan ‘Donnarine’ nekarien bome toegedien. Die verhoging van die EG van voedingsoplossings ten einde kwaliteit te verbeter is ‘n tegniek wat met groot suksses in die groentbedryf toegepas word. Hierdie tegniek het egter nie soortgelyke positiewe effekte op die nektarien vrugkwaliteit gehad nie. Produsente wat hul vrugkwaliteit wil verbeter behoort primêr te fokus op goeie produksiepraktyke soos akkurate voeding en besproeiing asook die korrekte tuinboukundige insette.

Dedicated to my parents, Terry and Dorothy Krige, without whom none of this would have been possible. I love you.

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# CHAPTER 1

## LITERATURE REVIEW: The nitrogen nutrition and seasonal mineral nutrient requirements of peaches and nectarines.

### 1. Introduction

Mengel and Kirkby (1987) define nutrition as the supply and absorption of chemical compounds needed for growth and metabolism, and nutrients as the chemical compounds required by an organism. In order for an element to be considered an essential plant nutrient three criteria proposed by Arnon and Stout (1939) must be met. These criteria are: a deficiency of the element must make it impossible for the plant to complete its life cycle, the deficiency must be specific for the element in question and the element must be directly involved in the nutrition of the plant, for example, as a constituent of a metabolite.

Based on the above mentioned criteria the elements known to be essential for higher plants are: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorous (P), sulphur (S), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), boron (B), chlorine (Cl), sodium (Na), silicon (Si), cobalt (Co) and nickel (Ni). Ni is the most recent candidate to be added to the list of 13 essential mineral elements for higher plants (Gerendás *et al.*, 1999). These chemical compounds can be split into macro- and micro-elements where the macro-elements C, H, O, Ca, Mg, K, S, N and P are required by plants in relatively high amounts while the micro-elements B, Cl, Cu, Fe, Mn, Mo, Zn and Ni are essential in smaller quantities (Terblanche, 1972; Mengel and Kirkby, 1987; Van der Watt and Van Rooyen, 1995; Gerendás *et al.*, 1999).

According to Mengel and Kirby (1987) N is one of the most widely distributed elements in nature, with the highest amount present in a fixed form in part of the earth's crust, while the atmosphere constitutes the second largest reservoir of N. Of the mineral

elements, plants require N in the greatest quantities (Du Preez, 1985). Adequate nitrogen is essential for normal flowering, vegetative growth and fruit growth, but too much nitrogen induces excessive vegetative growth, poor colour, poor fruit quality as well as reduced storage and shelf life (Swietlik, 2003). Nitrogen is a constituent of many biologically and physiologically important compounds in plants (Stassen *et al.*, 1981b) and is present in proteins, nucleic acids, chlorophylls, coenzymes and certain plant hormones such as indoleacetic acid and natural cytokynins (Du Preez, 1985). Approximately 5% of nitrogen in the plant exists as amino compounds, while an estimated 10% exists as nucleic acids and 80% to 85% in proteins (Scott Johnson and Uriru, 1998).

The importance of nitrogen nutrition cannot be over emphasized. This review will concentrate on the N nutrition of peaches and nectarines with specific reference to the patterns of N uptake and the role of N as a reserve in the tree as well as orchard nitrogen management regarding the N requirement and the timing of N application. In addition the seasonal requirement of other macro –and micro nutrients by peach and nectarine orchards will be discussed.

## 2. Nitrogen availability

The nitrogen cycle, as illustrated schematically in Figure 1, describes the transformation of nitrogen and nitrogen containing compounds in nature. The main processes in the cycle are N fixation, ammonification, nitrification, denitrification and assimilation and has been well documented by many authors (Mengel and Kirkby, 1987; Taiz and Zeiger, 1991; Salisbury and Ross**,** 1992; Marschner, 2002).

Nitrogen exists in several forms in our environment (Salisbury and Ross**,** 1992). In soils, N can exist in organic form, as ammonium ions ($NH_4^+$), nitrite ions ($NO_2^-$) or as nitrate ions ($NO_3^-$) (Scott Johnson and Uriru, 1998). As much as 90% of the N in soils may be in organic matter (Salisbury and Ross**,** 1992). Approximately 2% to 3% of the soil organic nitrogen is converted to $NH_4^+$ through ammonification annually (Scott Johnson and

Uriru, 1998). Subsequently, through the oxidative process of nitrification, $NH_4^+$ is converted first to $NO_2^-$ and then to $NO_3^-$ (Mengel and Kirkby, 1987; Scott Johnson and Uriru, 1998; Marschner, 2002). Optimal conditions for nitrification occur at soil temperatures between 27°C and 32°C, moderate soil water status and a pH ($H_2O$) between 6 and 7 (Scott Johnson and Uriru, 1998).

$NH_4^+$ and $NO_3^-$ ions are the major sources of N taken up by tree roots (Faust, 1989) and their availability is of utmost importance to N nutrition. $NO_3^-$ ions occur naturally at higher concentrations than $NH_4^+$ in the soil solution (Mengel and Kirkby, 1987). $NH_4^+$, on the other hand, can be adsorbed to the negatively charged soil cation-exchange complex (Neilsen & Neilsen, 2003). While most plant species, when grown under appropriate conditions, can effectively utilize either $NH_4^+$ or $NO_3^-$ as N source, differential response to the two ions have been reported for a wide variety of crops (Hageman, 1984). Kotzé *et al.* (1976, 1977) reported better growth of apple and peach seedlings with $NH_4^+$ as the sole source of N in acid soils or nutrient solutions containing aluminum. In studies of the uptake of $^{15}N$ labeled $NH_4^+$ and $NO_3^-$ by apple, apricot and nectarine trees, Kotzé *et al.* (1991) found that, in a system which contained equal amounts of $NH_4^+$ and $NO_3^-$, all three fruit types preferentially absorbed $NH_4^+$. This is in contrast to findings by Manolakis and Lüdders (1977) who reported better growth of apple trees in a nutrient culture with $NO_3$-N in comparison with $NH_4$-N. Edwards and Horton (1982) found that the ratio of $NH_4$-N to $NO_3$-N in the nutrient solution had a significant effect on the growth of peach seedlings, with best growth obtained when both ionic species were present.

In their review of the $NH_4^+$ and $NO_3^-$ nutrition of horticultural crops, Barker and Mills (1980), state the explanation for the differences found in the literature regarding the response to the two ions. The explanation is that, if the optimum conditions for the utilization of each source could be provided, the utilization of $NH_4^+$ and $NO_3^-$ forms of nutrition would be equivalent (Prianishnikov, 1951). Barker and Mills (1980) also discuss the factors influencing the acquisition of $NH_4^+$ and $NO_3^-$ as source of N.

Nitrogen may be lost from the soil through a variety of mechanisms. One of the most important sources of nitrogen loss from the soil occurs through leaching (Scott Johnson and Uriru, 1998). As explained earlier, the positively charged $NH_4^+$ ion may be bound to the negatively charged soil cation exchange complex. The $NO_3^-$ anion is highly mobile and not adsorbed by soil colloids (Barker and Mills, 1980) and therefore exists mainly in the soil solution (Neilsen & Neilsen, 2003). For this reason $NH_4^+$ cations do not move readily in the soil, even with heavy irrigation or rainfall (Scott Johnson and Uriru, 1998). $NO_3^-$ anions, on the other hand, are mobile in the soil as part of the soil solution and can be more readily leached from the root zone than $NH_4^+$ (Mengel and Kirkby, 1987; Scott Johnson and Uriru, 1998).

A second source of nitrogen loss occurs in gaseous form through the process of denitrification (Mengel and Kirkby, 1987; Scott Johnson and Uriru, 1998; Marschner, 2002). Many species of bacteria occurring in soils possess the capability to reduce nitrates to nitrogenous gasses (NO, $N_2O$, $N_2$) which are then released to the atmosphere (Mengel and Kirkby, 1987). Although the process of denitrification occurs naturally in soils, it is enhanced under anaerobic conditions since the bacteria involved use nitrates as a source of oxygen when $O_2$ is limited (Scott Johnson and Uriru, 1998). High soil moisture content, neutral soil pH, high soil temperatures, a low rate of oxygen diffusion as well as the presence of soluble organic matter and nitrates promote denitrification (Mengel and Kirkby, 1987).

## 3. Nitrogen uptake patterns and reserve role

In most cropping systems, available nitrogen is often a more limiting factor than any other nutrient (Barker and Mills, 1980) This may be especially true under local conditions as South African soils are usually deficient in N and because N is easily leached from the soil, N must be applied annually (Levin, 1977). Bearing peach trees require annual nitrogen application in order to maintain its nitrogen status. This is due to the fact that the tree cannot satisfy all its needs over more than one year with the nitrogen stored in the tree (Taylor and Van den Ende, 1969).

The specific elemental requirements for optimum growth, production and fruit quality per fruit kind and cultivar, especially under higher planting densities, need to be determined (Stassen and North, 2005). Weinbaum *et al.* (2001) discuss many methods of research in this regard, but state that the sequential excavation of trees coupled with biomass determinations and nutrient analysis is the only research method that can reliably indicate the amounts and seasonal patterns of tree nutrient uptake.

Many such nutrition studies have been conducted for a variety of crops. Peach trees (Stassen *et al.*, 1981a; Stassen *et al.*, 1981b; Stassen *et al.*, 1983; Stassen, 1987; Stassen and Stadler, 1988), apple trees (Batjer *et al.*,1952; Terblanche, 1972; Haynes and Goh, 1980), mango trees (Stassen *et al.*, 1997a; 1997b), avocado trees (Stassen *et al.*, 1997c), grapevines (Conradie, 1980; 1981), pear trees (Stassen and North, 2005) and pistachio trees (Rosecrance *et al.*, 1996) were all investigated. This review focuses on the work done on peach trees, but reference will be made to other crops where it is deemed applicable.

Stassen *et al.* (1981b) studied the seasonal changes in nitrogen fractions of two year old ‘Kakamas’ peach trees grown in sand culture. The seasonal pattern of total nitrogen content of the trees, showed two periods of nitrogen uptake, namely from three weeks before budbreak up to three weeks before the termination of shoot extension growth as well as from three weeks before up to three weeks after final leaf-drop. These two periods of rapid increase in total tree N are clear in Figure 2. At a later stage Stassen (1987) studied the macro-element content and distribution of 15 month old as well as 10 year old ‘Kakamas’ peach trees and again reported that nitrogen is taken up during spring and autumn.

The amount of N taken up during the early part of the season (spring) was not sufficient to supply all the requirements of the new, developing growth Stassen *et al.* (1981b). During the period from three to twelve weeks after bud-break the nitrogen content of the permanent structures (bark, wood and roots) decreased (Figure 2). This coincided with a sharp increase in the N content of the new growth (Figure 2). Nitrogen reserves were

therefore mobilized from the permanent structures during this stage and accounted for approximately 65% of the N increase in the new growth (Stassen *et al.* 1981b). The importance of N reserves in the early season is confirmed by Jordan *et al.* (2001) who studied the nitrogen uptake by young peach trees in relation to the management of carbon and nitrogen stores and found that growth during spring depended on the amount of nitrogen provided during the previous summer.

The above mentioned dependence of early season growth and development on nitrogen reserves has been illustrated for a variety of fruit crops other than peaches and nectarines. Terblanche (1972) reported similar results for apples. Titus and Kang (1982) stated that nitrogen and carbohydrate reserves provide energy and building blocks required by the initial growth of deciduous fruit crops before photosynthesis or significant root uptake of nitrogen can take place. Cheng *et al.* (2001) found that the new shoot and leaf growth in spring of 'Bartlett' pears is mainly determined by reserve nitrogen, not reserve carbohydrates. They also found that the utilization of reserve N for new shoot and leaf growth is dependant on the amount of reserve N, and is not affected by the current supply of nitrogen during springtime.

Soluble as well as insoluble forms of nitrogen have been reported as important sources of stored N in deciduous fruit trees. Oland (1954, 1959) for apples, Taylor and May (1967) for young peach trees and Taylor and Van den Ende (1967) for bearing peach trees concluded that N is mainly stored as a soluble N compound. Taylor and May (1967) did, however, suggest that a portion of the insoluble nitrogen fractions may also function as reserves. In contrast to this, Tromp (1970) as well as Tromp and Ovaa (1971, 1973), reported that protein nitrogen is the more important stored nitrogen in the bark of apple trees.

Arginine is the most common amino acid in peach trees and is the principle form of storage N during the dormant season (Scott Johnson and Uriru, 1998). Schulka (1962) described asparagine as a mobile form of N and an intermediate product in protein synthesis, while arginine was described as a reserve form of nitrogen in the apple tree.

During their studies of young ‘Kakamas’ peach trees Stassen *et al.* (1981b) also reported the seasonal changes in the total amount of protein nitrogen (Figure 3), soluble nitrogen (Figure 4), asparagine (Figure 5) and arginine (Figure 6). Their findings showed that soluble nitrogen appears to be the major source of nitrogen migrating to the new growth during the early part of the season, while protein nitrogen is probably redistributed from the bark and wood to the roots. The asparagine as well as arginine content of the permanent structures reached a peak during the dormant period after which its levels dropped from bud-break, as nitrogen fractions were utilized by the new growth and development (Stassen *et al.*, 1981b).

## 4. Orchard nitrogen management

### 4.1. Nitrogen requirement

During his study of the macro-element content and distribution in peach trees, Stassen (1987) determined the macro-element requirement of peach trees and, therefore, the fertilizer requirement. While some guidelines regarding the nutritional demands of deciduous fruit were available at that stage (Terblanche and Stassen, 1977; Lourens and Conradie 1981; Du Preez, 1984), these were based solely on calculations made from fruit analysis. Losses, however, also occur through leaf fall and pruning and provision should also be made for elements fixed in the permanent structures of the tree (Stassen, 1987). Weinbaum *et al.* (2001) state that the sequential excavation of trees coupled with biomass determinations and nutrient analysis is the only research method that can reliably indicate the amounts and seasonal patterns of tree nutrient uptake.

The nitrogen requirements of peach orchards as proposed by Stassen (1987) are as follows: Young, non-bearing, trees require 10.5 grams of N per kg of fruit produced while full bearing orchards require 5.6 grams of N per kg of fruit produced. The higher requirement by young trees was attributed to a larger leaf to fruit relationship as well as a higher level of fixation in the permanent structures (Stassen, 1987). At a later stage

Stassen (2001) proposed that 4.0kg of N is required to ensure normal growth and development for every ton of peaches produced.

Recently Woolridge (2007) reported that, on sandy, infertile soils, tree performance, yield and N utilisation in 'Keisie' peach orchards are likely to be optimised by the application of 8.4 grams of N per kg of fruit produced. This was not based on sequential excavation of trees coupled with biomass determinations and nutrient analysis as proposed by Weinbaum *et al.* (2001), but on observations during the fourth to seventh leaf of the orchard. According to Stassen (1987) it is normally accepted that approximately 30% of the applied nitrogen is not available to plant roots as a result of N losses such as leaching, volatilisation and ineffective placement. In the sandy, infertile site, as described by Woolridge (2007), losses may be even higher than 30%. If one deducts 30% from the 8.4 grams of N per kg of fruit produced as proposed by Woolridge (2007), the answer is 5.9 grams of N per kg of fruit. This is very close to the 5.6 grams of N per kg of fruit produced proposed by Stassen (1987), but higher than the 4.0kg of N per kg of fruit produced that was proposed later (Stassen, 2001).

## 4.2. Timing of nitrogen applications

As stated previously, nitrogen applications are required in order to provide sufficient nitrogen to deciduous fruit orchards for optimal production. Accurate timing of nitrogen fertilizer applications, when the sink demand is high, ensures better uptake and reduced leaching (Klein and Weinbaum, 2000). These applications must be made at a time when nitrogen will be sufficiently absorbed to have advantageous effects on tree growth and development (Stassen *et al.*, 1991a).

Stassen *et al.* (1981a) studied the effect of the timing and rate of nitrogen applications on the development and composition of peach trees. Their results showed that full applications of autumn nitrogen on peach trees resulted in earlier flowering and better fruit set than where the autumn nitrogen applications were reduced. Furthermore, they concluded that new growth and development during the start of the season, was to a large

extent dependent on stored nitrogen which, in turn, was dependant on the nitrogen application during the previous autumn.

Stassen *et al.* (1983) reported that at least 48% of the total annual N-requirement of a full bearing peach tree must be taken up during the post-harvest period in order to bring the tree to the same nitrogen level as the previous winter. Nitrogen reserves from the permanent structures are responsible for a substantial portion of the N increase in the new growth. Stassen *et al.* 1981b reported that N reserves accounted for approximately 65% of the N increase in the new growth, while Stassen *et al.* (1983) reported a value of 80%. This stresses the importance of sufficient autumn applications of nitrogen.

Stassen *et al.* (1987) indicated that there are two important stages when nitrogen needs to be applied to the soil in peach orchards. The first period is from bud movement during early spring, while the second period stretches from the termination of shoot elongation up to leaf drop. The second period is the post-harvest (autumn) period. Each of these periods should receive approximately 50% of the annual N requirement (Stassen *et al.*, 1987). These periods coincide with the periods of nitrogen uptake as discussed in the previous section. Woolridge (2007), however, for the same 'Keisie' peach orchard as described above, states that 60% of the total N requirement should be applied at full bloom, 30% approximately 42 days later, and the remaining 10% during autumn after the cessation of shoot growth. A possible explanation for the difference from the recommendations by Stassen (1987) is that these findings and recommendations were based on observations in a specific orchard and may be soil and site specific.

## 5. Seasonal mineral nutrient requirements

### 5.1. Macro nutrients

The annual nitrogen requirement of peaches and nectarines was discussed in section 4 of this review. Few publications provide quantitative guidelines regarding the macro nutrient requirements of peach and nectarine trees. Stassen (1987) studied young 15

month old as well as full bearing, large ten year old ‘Kakamas’ peach trees and proposed macro nutrient requirement guidelines based on his studies. These guidelines are presented in table 1.

At a later stage Stassen (2001) proposed the following guidelines, presented in kg element requirement per ton of fruit produced, for the macro nutrient requirement of full bearing peach trees: 4.0kg of N, 0.5kg of P, 3.5kg of K, 3.0kg of Ca, 0.7kg of Mg and 1.4kg of S.

Stassen *et al.* (1983) proposed that, by applying enough phosphorous (30mg.kg$^{-1}$) during soil preparation, P can be supplied for the whole commercial lifetime of the tree, as phosphorus is not lost through leaching.

### 5.2. Micro nutrients

Micro-elements, while required in smaller amounts than the macro-elements (Marschner, 1986), still fulfill very important roles in the plant. Very little literature is available on the seasonal micro nutrient requirements of peaches and nectarines. To date, nutrition studies have mainly focused on the macro nutrients and their role in peach and nectarine nutrition. Stassen (2001) did, however propose guidelines regarding the micro nutrient requirement of perennial fruit trees. The guidelines, per ton of fruit produced, are as follows: 28g of Fe, 6g of Mn, 1g of Cu, 8g of Zn, 8g of B and 0.8g of Mo.

## 6. Conclusions

Many authors have shown that nitrogen is one of the most important elements in the nutrition of higher plants, including peaches and nectarines. The supply of $NH_4^+$ and $NO_3^-$ to the tree is essential. This may be through the mineralization of organic matter present in the soil, or through the application of external sources of nitrogen e.g. organic or inorganic fertilizers.

The nitrogen uptake patterns by peach trees have been determined and defined as two periods of nitrogen uptake, namely from three weeks before bud-break up to three weeks before the termination of shoot extension growth as well as from three weeks before up to three weeks after final leaf-drop (Stassen *et al.* 1981b). The importance of nitrogen as a reserve in peach trees is well documented (Taylor and Van den Ende, 1969; Stassen, 1980; Stassen *et al.* 1981b; Stassen *et al.*, 1983; Stassen 1987) and the new growth and development during spring is dependant on nitrogen reserves to a large extent.

The sequential excavation of trees coupled with biomass determinations and nutrient analysis is the only research method that can reliably indicate the amounts and seasonal patterns of tree nutrient uptake (Weinbaum *et al.*, 2001). Stassen (1987) performed such studies and provided guidelines regarding the macro-element requirements of young as well as full bearing 'Kakamas' peach trees.

The nitrogen requirements of peach orchards as proposed by Stassen (1987) are as follows: Young trees require 10.5 grams of N per kg of fruit produced while full bearing orchards require 5.6 grams of N per kg of fruit produced. At a later stage Stassen (2001) proposed that 4.0kg of N is required to ensure normal growth and development for every ton of peaches produced. The previous work done on peach trees (Stassen *et al.*, 1981a; Stassen *et al.*, 1981b; Stassen *et al.*, 1983; Stassen, 1987) made use of large, widely spaced trees or trees grown in sand culture.

In addition to nitrogen, young peach trees require other macro nutrients in the following amounts, per ton of fruit produced: 1.1kg P, 5.5kg K, 7.6kg Ca and 2.8kg Mg. For full bearing peach trees these requirements are 0.4kg P, 3.2kg K, 3.0kg Ca and 0.7kg Mg according to Stassen (1987) and 0.5kg P, 3.5kg K, 3.0kg Ca, 0.7kg Mg and 1.4kg S according to Stassen (2001). Very little literature is available on the seasonal micro nutrient requirements of peaches and nectarines, but Stassen (2001) proposed the following guidelines, per ton of fruit produced: 28g of Fe, 6g of Mn, 1g of Cu, 8g of Zn, 8g of B and 0.8g of Mo. The above mentioned guidelines are based on sound research

and will, in all likelihood, hold true for older, widely spaced orchard where fertiliser is applied through broadcasting.

Many modern South African nectarine orchards are established at relatively high densities and pruned and trained as central leader, slender spindle or two-leader V-system trees. Due to the differences in tree architecture (tree volume and light utilization), one may expect that, currently, nutrient losses due to pruning and fixation in the permanent structures may differ from previous findings. If this holds true, differences in the mineral nutrient demand can exist, when comparing these smaller trees to the large trees of the past.

Accurate water and fertilizer management is essential in highly intensive orchard systems to enable the manipulation of both reproductive and vegetative development, to ensure the possibility of higher quality fruit, with longer storage potential, and to reduce pollution and costs (Tagliavini and Marangoni, 2000). Daily drip fertigation through pulsating the application of a nutrient solution many times per day has gained popularity in the South African fruit industry, as it holds many advantages for the producer. The above mentioned water and nutrient management strategy is also known as the open hydroponic system (OHS). The term open indicates that the nutrient solution is not recycled in the system.

The open hydroponic system is a holistic system and the emphasis is on being able to manipulate the tree with a smaller rooting system, water and nutrients (Woods, 1999). According to Stassen *et al.* (1999) open hydroponics is a sensitive nutrient and moisture management system with which a high degree of control over the vegetative and reproductive development of the tree can be exercised. The advantages of the open hydroponic system culminates in cost saving in respect of soil preparation and maintenance of the rooting volume, utilization of poor quality water and soils, better utilization of nutrients and water and better control over the product (Woods, 1999). Pijl (2001) compared the root density of citrus trees grown under micro-irrigation, conventional drip fertigation and daily drip fertigation. The root density under daily drip

fertigation, with a balanced nutrient solution, was found to be higher than the other treatments (Pijl, 2001).

With this relatively new water and nutrient management approach, one can hypothesise that nutrient losses due to leaching and denitrification of N may by greatly reduced as a result of more effective nutrition and a more effective root system. If this holds true, one can expect that new daily drip fertigated orchards may require nutrients in different amounts than proposed in the past.

Guidelines regarding the elemental requirements for optimum growth, production and fruit quality per fruit kind and cultivar, especially under higher planting densities, need to be determined (Stassen and North, 2005).

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## Tables

**Table 1:** Macro elements in kg required by peach trees to produce 1 ton of fruit (Stassen, 1987).

| **Tree Age** | **Macro element requirement (kg/ton of fruit produced)** | | | | |
|---|---|---|---|---|---|
| | **N** | **P** | **K** | **Ca** | **Mg** |
| Young tree | 10.5 | 1.1 | 5.5 | 7.6 | 2.8 |
| Full bearing tree | 5.6 | 0.4 | 3.2 | 3.0 | 0.7 |

**Figures**

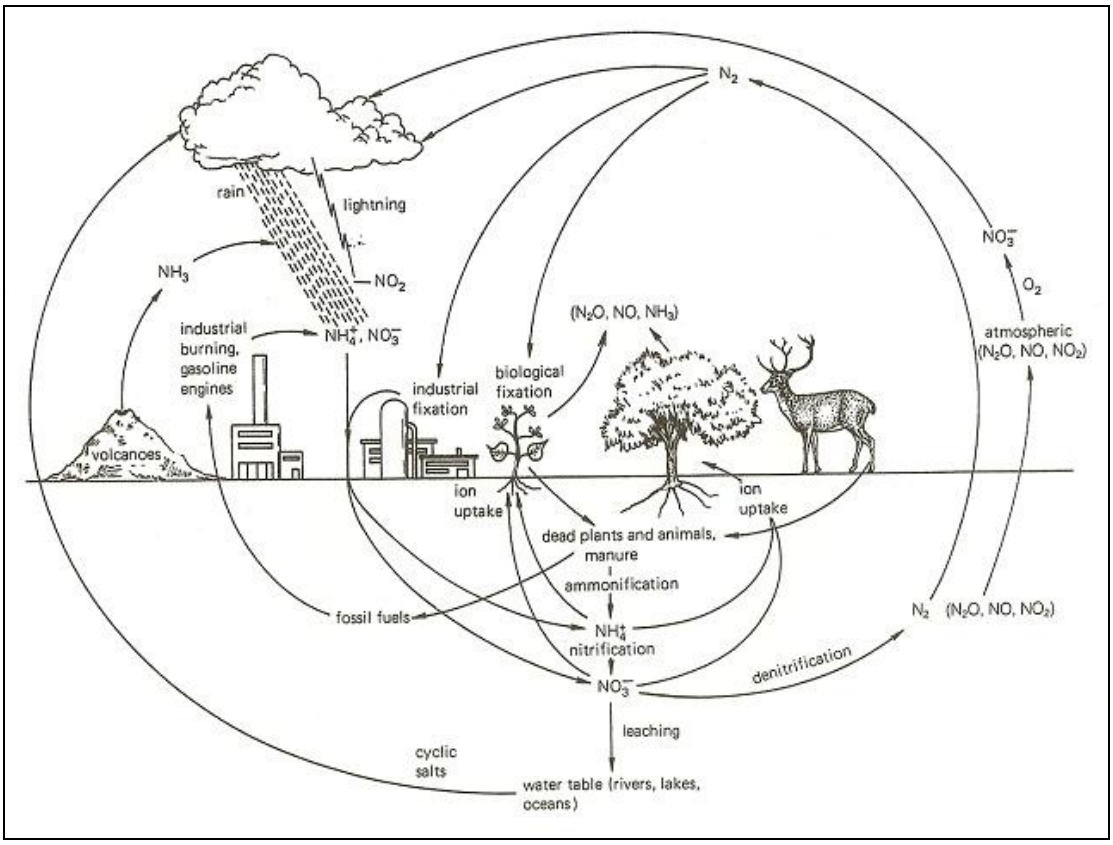


Figure 1: A schematic representation of the nitrogen cycle (Salisbury and Ross, 1992).

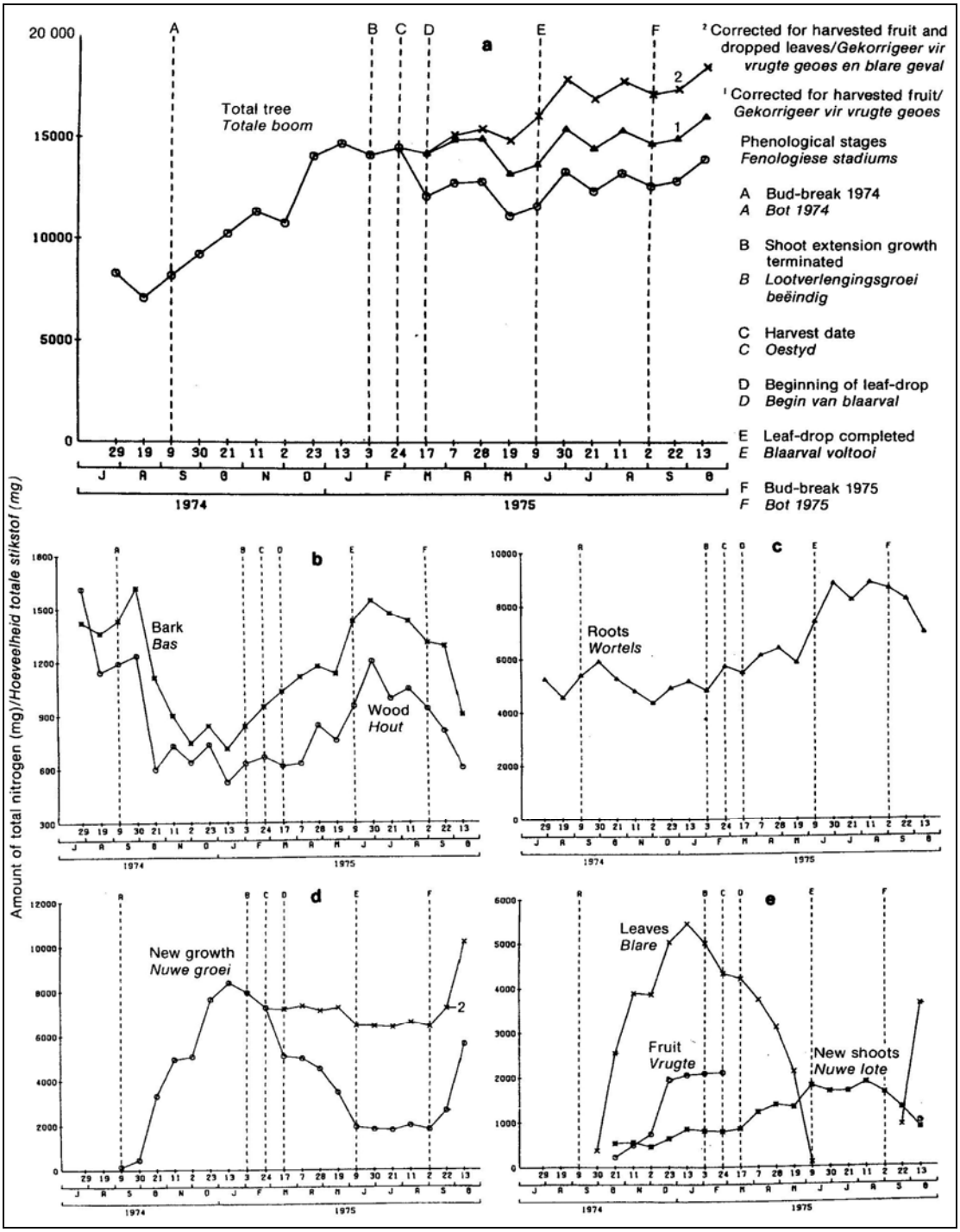


Figure 2: Seasonal changes in the amount of total nitrogen in two year old 'Kakamas' peach trees grown in sand culture (Stassen *et al.*, 1981a).

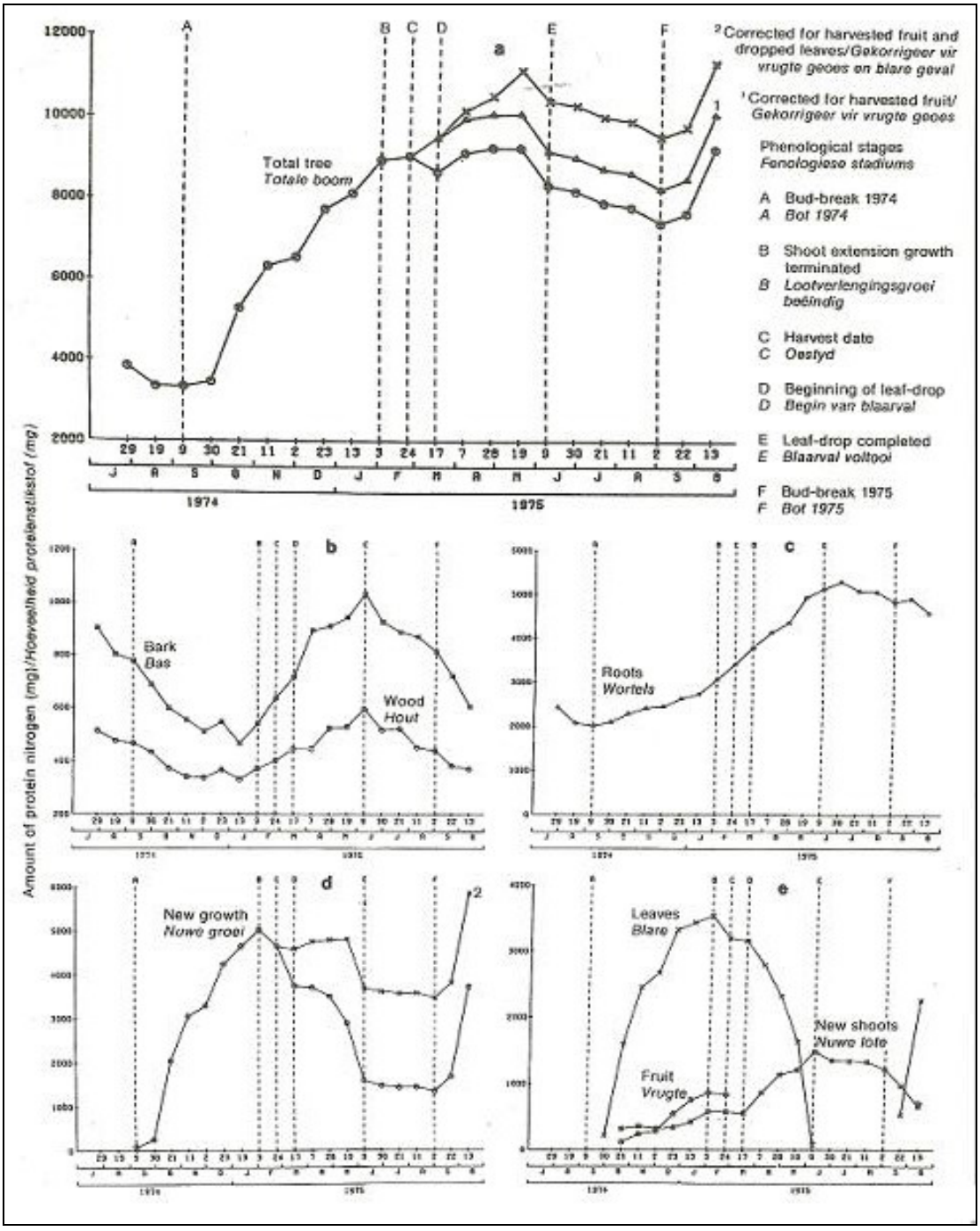


Figure 3: Seasonal changes in the amount of protein nitrogen in two year old 'Kakamas' peach trees grown in sand culture (Stassen *et al.*, 1981a).

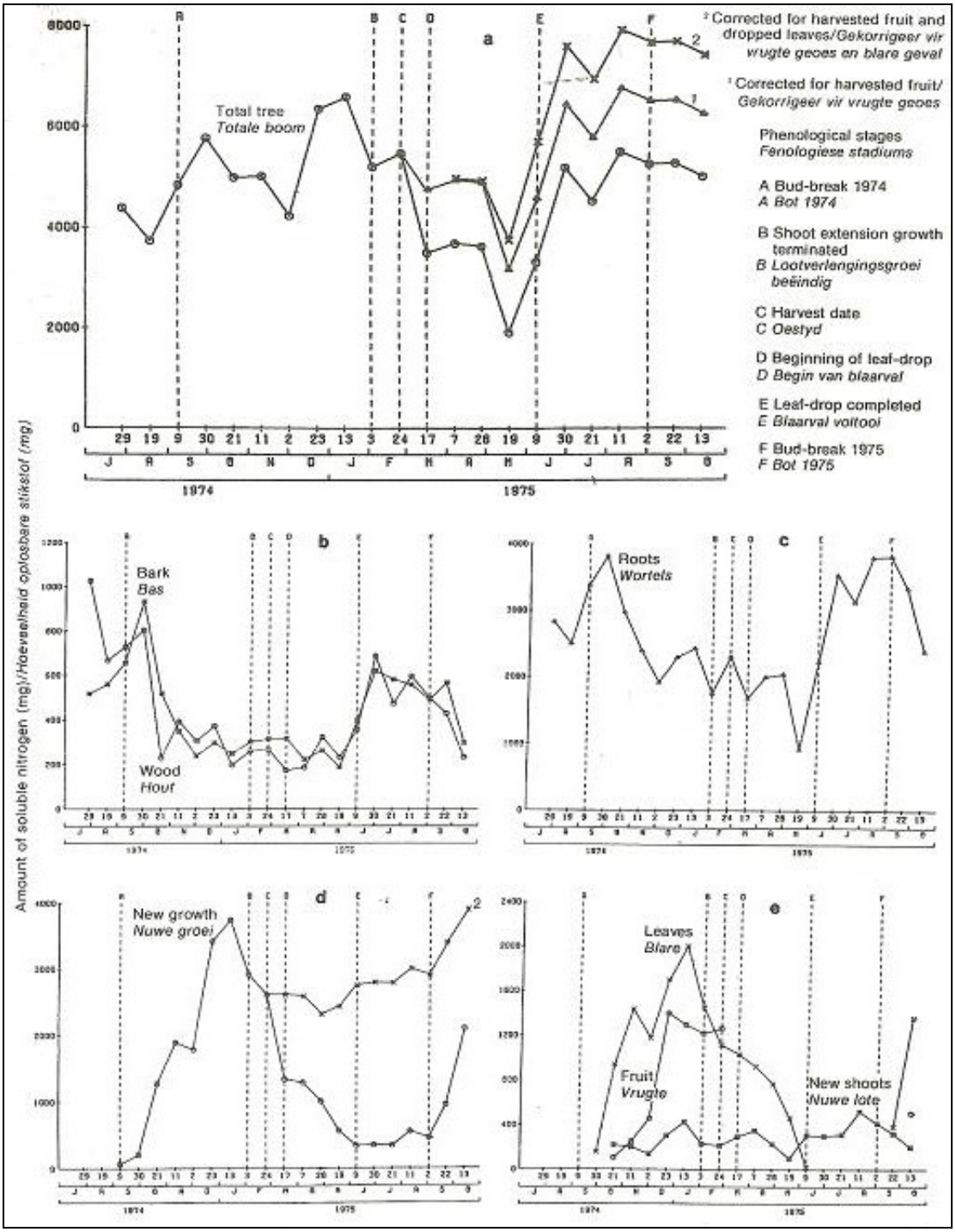


Figure 4: Seasonal changes in the amount of soluble nitrogen in two year old ‘Kakamas’ peach trees grown in sand culture (Stassen *et al.*, 1981a).

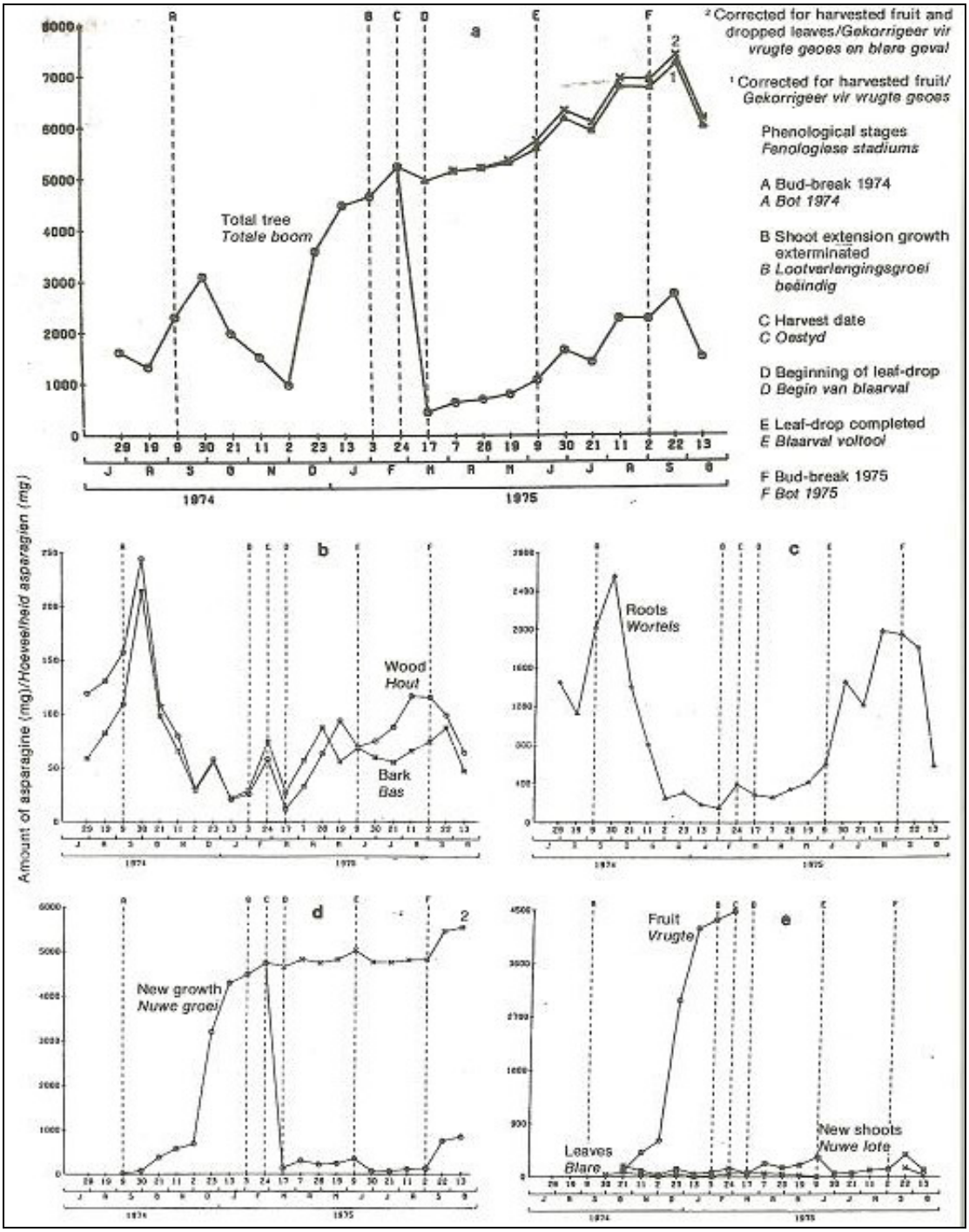


Figure 5: Seasonal changes in the amount of asparagine in two year old ‘Kakamas’ peach trees grown in sand culture (Stassen *et al.*, 1981a).

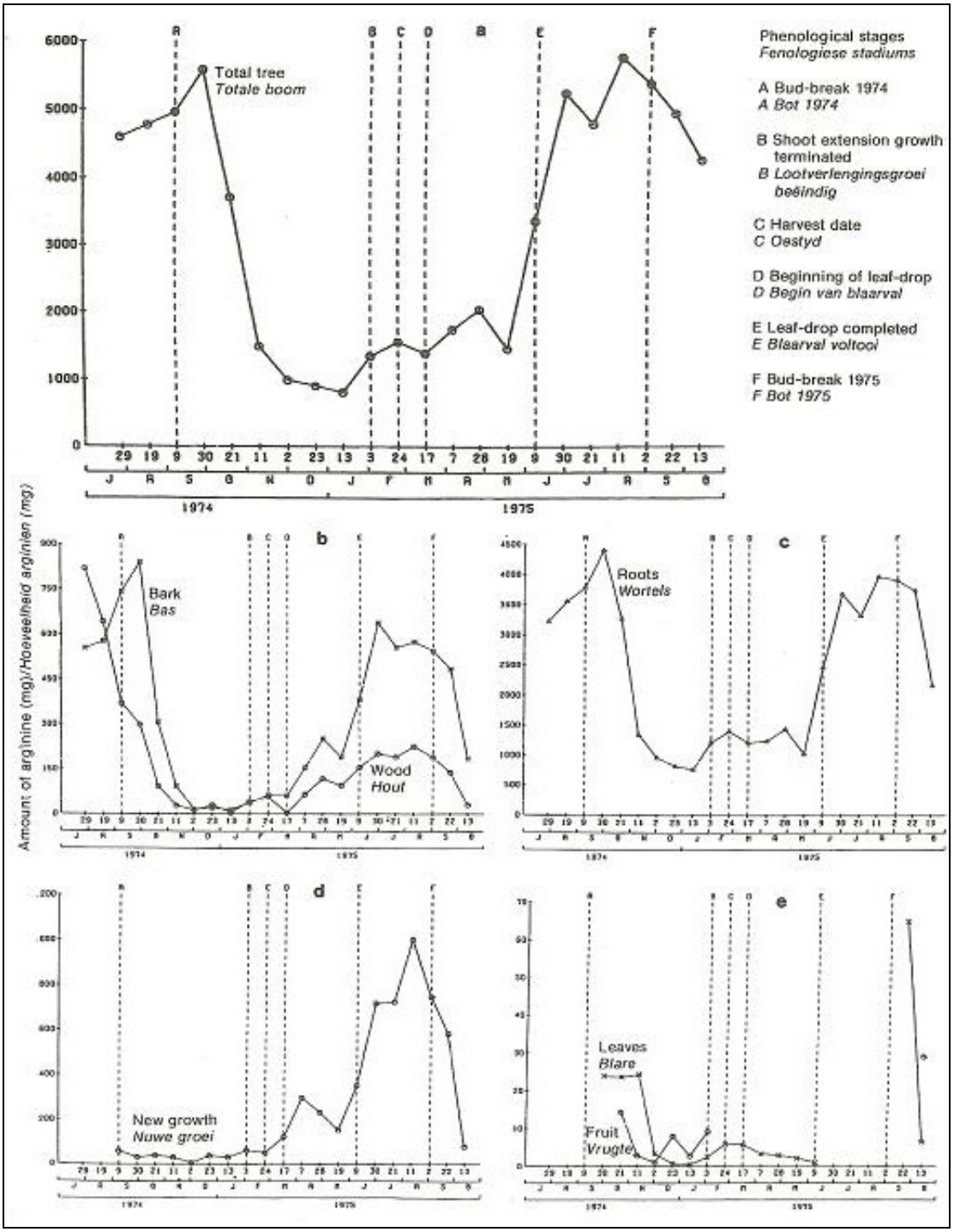


Figure 6: Seasonal changes in the amount of arganine in two year old ‘Kakamas’ peach trees grown in sand culture (Stassen *et al.*, 1981a).

## GENERAL HYPOTHESYS AND OBJECTIVES

### 1. Chapters 2 through 4

Previous research into the uptake, distribution and requirement of mineral nutrients by peach trees (Stassen *et al.*, 1981a; Stassen *et al.*, 1981b; Stassen *et al.*, 1983; Stassen, 1987; Stassen and Stadler, 1988) made use of large, widely spaced trees, or trees grown in sand culture. These studies concentrated on the essential macro nutrients and the reserve role as well as the distribution of micro nutrients in peach and nectarine trees is to date unsure.

Many modern South African nectarine orchards are established at relatively high densities and pruned and trained as central leader, slender spindle or two-leader V-system trees. These trees are smaller, carry less permanent structural wood and utilize light more efficiently than the older trees mentioned above. The difference in tree architecture may have an influence on the distribution of nutrients within the tree as well as the reserve status and nutrient requirement of the trees. This, combined with more efficient nutrition through the open hydroponic system (Stassen *et al.*, 1999; Woods, 1999), provides reason to re-evaluate the mineral nutrition of the modern nectarine orchard.

We hypothesise that the mineral nutrient distribution and requirements of modern higher density nectarine orchards differs from traditional orchards with large, widely spaced trees. In order to test this hypothesis, trials were conducted with the objective of studying the macro –and micro nutrient uptake and distribution by higher density nectarine trees through the sequential excavation of trees (Weinbaum *et al.*, 2001). A subsequent objective was to, through calculations of nutrient uptake, losses and fixation, provide guidelines regarding the seasonal macro -and micro nutrient demands of modern nectarine orchards.

## 2. Chapter 5

The ultimate objective of the production, handling and distribution of fresh fruits and vegetables is to satisfy customers and quality is related to customer satisfaction (Shewfelt, 1999). While fruit size and colour has always been important, in the last decade taste, aroma and food safety as fruit quality parameters have grown in importance in American and European markets. The degree of liking and consumer acceptance was found to be associated with ripe soluble solids concentration (RSSC) regardless of ripe titratable acidity (RTA) (Crisosto and Crisosto, 2005). Consumers find peaches and nectarines with 11% SSC or higher highly acceptable (Claypool, 1977).

Many authors have shown that an increase in the pre-harvest nutrient solution EC results in an increase in the total soluble solids (TSS) content of a variety of fruit types. This was demonstrated for tomatoes (Auerswald *et al.*, 1999; Caurtero and Rafael, 1999), sweet peppers (Janse, 1989), cucumbers (Chartzoulakis, 1995). Salinity and nutrient solution concentration trials were also conducted on muskmelons (Combrink *et al.*, 1995), egg plants (Chartzoulakis, 1995), celery (Pardossi *et al.*, 1999) and lettuce (Serio *et al.*, 2001).

Besset *et al.* (2001) showed that water stress during the final stage of rapid fruit growth could result in an improvement in peach taste. We hypothesise that, through increasing the pre-harvest nutrient solution EC provided through an open hydroponic system, the TSS of nectarine fruit can be increased. In order to test this hypothesis, four different nutrient solution EC levels applied to nectarine trees for three periods of different length during the final stage of rapid fruit growth were studied over two seasons. The aim was to determine whether raising the EC of the nutrient solution supplied to the trees for a certain period before harvest would result in an increase in TSS.

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# CHAPTER 2

## Macro-element uptake and distribution by full bearing 'Donnarine' nectarines under pulsating drip fertigation.

### 2.1. Introduction

Mengel and Kirkby (1987) define nutrition as the supply and absorption of chemical compounds needed for growth and metabolism, and nutrients as the chemical compounds required by an organism. These chemical compounds can be split into macro- and micro-elements where the macro-elements C, H, O, Ca, Mg, K, S, N and P are required by plants in relative high amounts (Terblanche, 1972; Mengel and Kirkby, 1987; Van der Watt and Van Rooyen, 1995). This paper focuses on the uptake and distribution of the macro-elements N, P, K, Ca and Mg by full bearing 'Donnarine' nectarine trees.

The macro-elements all fulfill important roles in the plant as will be discussed here. According to Mengel and Kirby (1987) nitrogen is one of the most widely distributed elements in nature, with the highest amount present in a fixed form in part of the earth's crust, while the atmosphere constitutes the second largest reservoir of N. Nitrogen is a constituent of many biologically and physiologically important compounds in plants (Stassen *et al.*, 1981b) and is present in proteins, nucleic acids, chlorophylls, coenzymes and certain plant hormones such as indoleacetic acid and natural cytokynins (Du Preez, 1985). Approximately 5% of nitrogen in the plant exists as amino compounds, while an estimated 10% exists as nucleic acids and 80% to 85% in proteins (Scott Johnson and Uriru, 1998). Of the mineral elements, plants require nitrogen in the greatest quantities (Du Preez, 1985). Stassen *et al.* (1981b) define two periods of nitrogen uptake in 'Kakamas' peach trees, namely from three weeks before budbreak up to three weeks before the termination of shoot extension growth as well as from three weeks before up to three weeks after final leaf-drop (addendum A, figure1).

The three principal forms of phosphorous in the plant are: in RNA and DNA molecules, in cell membranes and in ATP molecules (Scott Johnson and Uriru, 1998).

Stassen and Stadler (1988) found that phosphorous uptake by ‘Kakamas’ peach trees was relatively slow during the three-week period after budbreak, but increased thereafter up to harvest (addendum A, figure 2).

Potassium exists in large quantities in both leaf and fruit tissues. Although one of its functions is to activate enzymes, most potassium ions are not tied up in complex molecules, but are used in the ionic form by young, actively growing cells and also guard cells, as a solute, to help maintain turgor (Scott Johnson and Uriru, 1998). Potassium uptake appears to be proportional to vegetative growth, reaching its maximum in early summer (Scott Johnson and Uriru, 1998). According to Stassen (1987) potassium uptake by peach trees takes place optimally from after bud movement up to the time of harvest. Stassen and Stadler (1988) found that potassium uptake by ‘Kakamas’ peach trees was relatively slow during the three-week period after budbreak, but uptake increased markedly from thereafter up to harvest (addendum A, figure 3).

Calcium is involved in many plant processes including cell elongation, cell division, germination, pollen growth and senescence, but one of its most important functions is the maintenance of membrane permeability and cell integrity (Scott Johnson and Uriru, 1998). Calcium is taken up passively by growing roots and apparently only the region just behind the tip of growing roots is capable of Ca uptake, therefore factors inhibiting root growth also inhibits its uptake (Scott Johnson and Uriru, 1998). Stassen and Stadler (1988) found that the total calcium increase in ‘Kakamas’ peach trees was relatively slow during the first three weeks after bud-break. This was followed by rapid accumulation from three weeks after bud-break up to harvest. A further increase in total calcium was found to occur from three weeks to nine weeks after harvest (addendum A, figure 4).

Magnesium functions as an activator of many important enzyme reactions and as a major component of the chlorophyll molecule, however, as much as 70% of the magnesium in the plant is associated with diffusible anions (Scott Johnson and Uriru, 1998). Stassen and Stadler (1988) found that the magnesium uptake by ‘Kakamas’ peach trees was relatively slow during the first three weeks after bud-break. This was

followed by a period of rapidly increasing uptake from three weeks after bud-break up to harvest. Uptake was low in the post-harvest period (addendum A, figure 5).

The previous research into the uptake and distribution of macro-elements by peach trees (Stassen *et al.*, 1981a; Stassen *et al.*, 1981b; Stassen *et al.*, 1983; Stassen, 1987; Stassen and Stadler, 1988) made use of large, widely spaced trees, or trees grown in sand culture. Many modern South African nectarine orchards are established at relatively high densities and pruned and trained as central leader, slender spindle or two-leader V-system trees. Summer pruning is done to remove unwanted growth and water shoots, thus improving light distribution within the tree. These modern trees are smaller and carry less permanent structural wood than the older trees mentioned above.

The roles that the macro-elements play in the physiology of the trees are not expected to differ between the larger and the smaller, more modern trees. The difference in tree architecture may, however, have an influence on the distribution of nutrients within the tree as well as the reserve status of the trees.

The objective of this trial was to study the macro-element uptake and distribution by higher density nectarine trees through the sequential excavation of trees (Weinbaum *et al.*, 2001), and to compare the data to previous work done with larger peach trees of different architecture.

## 2.2. Materials and methods

Full bearing ‘Donnarine’ nectarine trees planted in July 2000 in a commercial central leader orchard (4.5m by 1.5m) near Prince Alfred Hamlet, Western Cape region, South Africa (33º21’S. 19º18’E) were used in the trial. A straw mulch is standard for the whole orchard and the trees receive water and nutrients through a pulsating drip fertigation system (open hydroponics) with nutrient recommendations based on prior publications (Stassen 1980, 1987, 2001; Stassen *et al.*, 1981a, 1981b; Stassen and Stadler 1988), tree performance as well as leaf and soil analysis. The seasonal irrigation requirement of the nectarine trees was determined by means of long term evaporation data and the use of crop factors. The farm management conducted the

irrigation scheduling with the help of capacitance soil moisture probe readings, weather station data and regular soil profile investigations to assess the situation in the soil. The orchard received a total of 3420.4 $m^3$/ha for the season. Nine trees in the orchard were selected at random for the trial during the winter of 2004. During dormancy three complete trees were excavated and divided into bearing wood, older scaffold limbs, stem with bark, thick roots and fine roots. Subsequent excavations of three whole trees each followed during pip hardening and at harvest (22 December 2004, Southern hemisphere) where new shoots, leaves and fruit were included. The fresh weight of each part was determined. A weighed fresh representative sample of each part of each tree was dried at 70ºC until constant dry mass was achieved. Total tree dry weight was calculated. Fruit samples were freeze-dried prior to mineral analysis. Dried samples were subjected to mineral analysis for the macro-elements nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg) by a commercial laboratory (BemLab Pty. Ltd, Somerset West, South Africa). The data was used to calculate the macro-element content of each part of each tree. Statistical analysis was conducted using SAS (Statistical Analysis System) statistical software (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, NC).

## 2.3. Results and discussion

### 2.3.1. Dry weight

Table 1 indicates the actual dry weight of the different tree parts in kg per tree during winter, at pip hardening and at harvest. During winter, the total tree dry weight was 10.36kg; consisting of the bearing wood, scaffold branches, stem and roots. The stem (6.07kg) contributed the largest portion while the roots contributed a total of 3.30kg.

The total dry weight of the permanent structure did not change significantly from winter to pip hardening. The total tree dry weight increased to 12.44kg at pip hardening. This is almost completely due to the development of 2.43kg of fruit, leaves and new shoots during this period.

From pip hardening to harvest the total tree dry weight increased to 17.57kg. Again new growth (fruit, leaves and new shoots) contributed the largest portion of this

increase at 3.55kg. Fruit growth contributed 2.94kg or 83% of the increase in new growth dry weight from pip hardening to harvest. The permanent structures did, however, also increase in dry weight to a total of 11.57kg for the bearing wood, scaffold branches, stem and roots.

### 2.3.2. Nitrogen

Table 2a and 2b indicates the actual N content of the different tree parts in g per tree as well as the N distribution in the tree during winter, at pip hardening and at harvest. In winter the total nitrogen (N) content of the 'Donnarine' nectarine trees was 80.65 g per tree, located in the permanent structure consisting of the bearing wood, scaffold branches, stem and roots. At this stage 30.3% of the N was located in the stem while the thick and fine roots respectively contained 40.2% and 21.3%, a combined total of 61.5% for the roots.

As the season progressed to pip hardening, the total N content increased to 119.88 g per tree through the uptake of 39.23 g per tree. The leaves now contained the most N (43.4%) while the root N contribution dropped from 61.5% to 20.1%. The fruit contained 9.3% of the total N at pip hardening. The permanent structure of the tree contained 52.78 g of N per tree at pip hardening, representing a decrease of 27.87 g per tree from winter. At pip hardening the total N found in the new growth (fruit, leaves and new shoots) was 67.10 g per tree, while the N uptake from winter to pip hardening was 39.23 g per tree. This indicates that new growth from winter to pip hardening is largely dependent on N reserves in the tree. Of the nitrogen found in the new growth at this stage, 41.5% or 27.87 g of N per tree, was translocated from the permanent structure of the tree as reserves. This is 18.5% less than the 60% found by Stassen (1980).

From pip hardening to harvest the N content increased further by 35.11 g per tree to a total of 155.00 g per tree. The fruit contribution to the total N content increased from 9.3% to 20.1% while the leaf N contribution dropped from 43.4% to 34.1%. From pip hardening to harvest the actual leaf N content increased very slightly from 52.08 to 52.78 g per tree while the N content of new shoots increased by 2.92 g per tree. Most (19.99 g per tree or 56.9%) of the 35.12 g of N per tree that was taken up from pip

hardening to harvest went to the fruit while 8.3% and 2.0% went to the new shoots and leaves respectively. During the same period the N content of the permanent structure of the tree increased by 11.50 g per tree to 64.28 g per tree.

### 2.3.3. Phosphorous

Table 3a indicates the actual P content of the different tree parts in g per tree during winter, at pip hardening and at harvest. Table 3b indicates the P distribution at the same stages. In winter the total phosphorous (P) content of the 'Donnarine' nectarine trees was 9.58 g per tree, located in the permanent structure consisting of the bearing wood, scaffold branches, stem and roots. During dormancy 21.0% of the P was located in the stem while the thick and fine roots respectively contained 48.3% and 22.5%, a combined total of 70.8% for the root phosphorous content.

From winter to pip hardening, the uptake of phosphorous increased the total P content by 3.80 g per tree to 13.38 g per tree. The new growth (fruit, leaves and new shoots) contained 5.85 g P per tree at this stage. This means that 35.0% or 2.05 g per tree of the P in the fruit, leaves and new shoots came from reserves in the permanent structure of the tree, while uptake contributed the remaining 65.0%. This compares very well to previous work by Stassen *et al.* (1983) who found that 43% of the phosphorous requirement for new growth of peach trees during the first eight weeks after budbreak came from redistribution from the permanent structure, especially the roots. The distribution of P in the tree also changed from winter to pip hardening. At this stage the leaves contained the most P (27.3%), the fruits contained 10.4% and the root P contribution dropped from 70.8% in winter to 29.7% due to the translocation of P reserves from the roots to new growth.

From pip hardening to harvest the total P content increased to 17.54 g per tree, representing 4.16 g per tree P uptake from pip hardening to harvest. The largest proportion, 2.6 g per tree or 62.5%, of the P that was taken up from pip hardening to harvest went to the fruit, while 1.90 g or 45.7% went to the permanent structure. The fruit contribution to the total P content increased from 10.4% to 22.8% while the leaf P contribution dropped from 27.3% to 16.6%.

### 2.3.4. Potassium

Table 4a and 4b indicates the actual K content of the different tree parts in g per tree as well as the K distribution in the tree during winter, at pip hardening and at harvest. In winter the total potassium (K) content of the 'Donnarine' nectarine trees was 19.49 g per tree, located in the permanent structure consisting of the bearing wood, scaffold branches, stem and roots. Most (48.5%) of the K was located in the stem, while the thick and fine roots respectively contained 18.6% and 18.8%, a combined total of 37.4% for the root potassium contribution.

As the season progressed from winter to pip hardening the total K content increased to 79.32 g per tree at pip hardening, representing an uptake of 59.83 g K per tree. The total K in new growth (fruit, leaves and new shoots) was 61.11 g per tree at this stage. This means that only 1.28 g of K per tree or 2.1% in the new growth originated from K reserves translocated from the permanent structure. This is markedly less than the amount presented by Stassen *et al.* (1983) who found that, in full-bearing peach trees, 40% of the K required for new growth during the first eight weeks after bud-break was obtained from reserves in the permanent structure of the tree. The distribution of K in the tree also changed from winter to pip hardening. At pip hardening the leaves contained the most K (59.2%), while the stem K contribution dropped from 48.5% in winter to 11.9%. The roots and the fruit contained 6.1% and 13.20% of the K in the tree respectively.

From pip hardening to harvest the K content increased to 126.14 g per tree through the uptake of 46.82 g per tree. The fruit contribution to the total K content increased from 13.2% to 43.3% while the leaf K contribution dropped from 59.2% to 33.4%. The amount of K that was accumulated in the fruit (44.12 g per tree) from pip hardening to harvest represents 94.2% of the total K that was taken up during the same period. The leaves exhibited a slight decrease of 4.91 g per tree from pip hardening to harvest, while the K content of the new growth increased by 1.82 g per tree to 5.48 g. The decrease in leaf K content indicates that some K was translocated from the leaves to the rest of the tree during this period.

### 2.3.5. Calcium

Table 5a indicates the actual Ca content of the different tree parts in g per tree during winter, at pip hardening and at harvest. Table 5b indicates the Ca distribution at the same stages. In winter the total calcium (Ca) content of the 'Donnarine' nectarine trees was 20.41 g per tree, located in the permanent structure (bearing wood, scaffold branches, stem and roots). Most (43.3%) of the Ca was located in the stem while the thick and fine roots respectively contained 16.4% and 8.2%, a combined total of 24.6% for the root calcium contribution. The branches contained 32.1% of the total Ca of which 21.4% was located in the older scaffold branches and 10.6% in the bearing wood.

As the season progressed from winter to pip hardening the total Ca content increased by 22.19 g per tree to 42.60 g per tree. The total Ca in new growth (fruit, leaves and new shoots) was 22.84 g per tree at this stage. This means that only 0.65 g of Ca per tree or 2.9% in the new growth represents Ca reserves translocated from the permanent structure. The leaves contained the most Ca (44.5%), the roots contained 10.3% and the fruit contained 1.99% of the total Ca at pip hardening. From pip hardening to harvest the Ca content increased by a further 15.66 g per tree to 58.26 g per tree. The fruit contribution to the total Ca content increased from 2.0% to 2.7%.

At harvest the Ca content of the new shoots (9.75 g per tree) was more than three times more than at pip hardening (3.05 g per tree). While the leaf Ca contribution dropped from 44.5% to 34.5% from pip hardening to harvest, the actual Ca content of the leaves increased slightly by 1.14 g per tree.

### 2.3.6. Magnesium

Table 6a and 6b indicates the actual Mg content of the different tree parts in g per tree as well as the Mg distribution in the tree during winter, at pip hardening and at harvest. In winter the total magnesium content of the 'Donnarine' nectarine trees was 4.67 g per tree located in the permanent structure (bearing wood, scaffold branches, stem and roots). Most (43.1%) of the Mg was located in the stem while the thick and fine roots respectively contained 27.4% and 13.0%, a combined total of 40.4% for the

root magnesium contribution. At this stage the older scaffold branches contained 10.7% of the Mg and 5.8% was located in the bearing wood, a total of 16.5% for the branches.

From winter to pip hardening the total Mg content increased to 11.57 g per tree through the uptake of 6.90 g per tree. The total Mg in new growth (fruit, leaves and new shoots) was 7.12 g per tree at this stage. This means that 0.21 g of Mg per tree or 3.0% of the Mg in the new growth originated from Mg reserves in the permanent structure. At pip hardening the leaves contained the most Mg (50.9%), the roots contained 11.0%, and the fruit contribution was 6.0%.

From pip hardening to harvest the Mg content increased by a further 11.57 g per tree to 14.54 g per tree. The fruit contribution to the total Mg content increased from 6.0% to 15.9%. The actual Mg content of the new growth (1.10 g per tree) was approximately double what it was at pip hardening (0.53 g per tree). The leaf Mg contribution dropped from 50.9% to 40.5%, but the actual Mg content of the leaves stayed constant at 5.89 g per tree.

## 2.4. Conclusion

A large portion, 41.5%, of the nitrogen manifested in the new growth (fruit, leaves and developing shoots) from winter up to pip hardening came from N reserves in the permanent structure. Even though this figure is lower than the 60% found by Stassen (1980), it is still a substantial amount. This underlines the importance of N reserves in the permanent structures of the nectarine tree. The roots were the most important source of nitrogen reserves, with the root contribution to the total N content of the tree decreasing from 61.5% during dormancy, to 20.1% at pip hardening.

The permanent structures were also an important source of phosphorous reserves. Of the P in the fruit, leaves and new shoots at pip hardening, 35.0% came from reserves in the permanent structure of the tree while root uptake contributed the remaining 65.0%. From dormancy to pip hardening the root contribution to the total amount of P in the tree dropped from 70.8% to 29.7%, indicating that the roots were the main source of phosphorous reserves. This compares favourably to previous work by

Stassen *et al.* (1983) who found that 43% of the phosphorous requirement for new growth of peach trees during the first eight weeks after budbreak came from redistribution from the permanent structure, especially the roots.

Stassen *et al.* (1983) found that, in full-bearing peach trees, 40% of the K required for new growth during the first eight weeks after bud-break was obtained from reserves in the permanent structure of the tree. During this trial 2.1% of potassium found in the new growth at pip hardening represented K reserves translocated from the permanent structure. This is markedly less than the amount presented by Stassen *et al.* (1983), but supports the statement made by Scott Johnson and Uriru (1998) that potassium uptake appears to be proportional to vegetative growth, reaching its maximum in early summer. Nutritional program must supply sufficient K from the beginning of the season as K did not act as a reserve. From pip hardening to harvest the fruit represented the most important sink for K. This coincides with the period of rapid fruit growth in stone fruit and emphasizes that K nutrition must be optimal during this phase to ensure that fruit size is not adversely affected.

At pip hardening only 2.9% of Ca in the new growth represented Ca reserves translocated from the permanent structure from winter to pip hardening. This indicates that Ca did not have an important role as reserve in the nectarine trees. This confirms findings by Stassen *et al.* (1983), who stated that new growth is dependant entirely on Ca uptake during the season. It is important that Ca be available for root uptake during the early part of the season where Ca is involved in many plant processes including cell elongation, cell division, germination and pollen growth.

Of the Mg in the new growth (fruit, leaves and new shoots) at pip hardening, 3.0% came from reserves in the permanent structure of the tree. This is substantially lower than the 38% found by Stassen *et al.* (1983), and very similar to the Ca level discussed above. Magnesium must, therefore, also be available for uptake from the beginning of the season as the new growth was found to be highly dependant on Mg uptake.

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## Tables

**Table 1:** The dry weight (kg) of full bearing 'Donnarine' nectarine trees in a higher density (4.5m by 1.5m) orchard at three phenological stages.

| Tree part | Dry weight (kg per tree) | | |
|---|---|---|---|
| | **Winter** | **Pip hardening** | **Harvest** |
| Fruit | - | 0.70 C | 3.63 B |
| Leaves | - | 1.40 B | 1.59 CD |
| New shoots | - | 0.34 C | 0.76 CD |
| Subtotal (new growth) | - | 2.43 | 5.98 |
| Bearing wood | 0.22 C | 0.40 C | 0.78 CD |
| Scaffold branches | 0.77 C | 0.75 C | 1.41 CD |
| Stem | 6.07 A | 6.68 A | 6.82 A |
| Thick roots | 2.13 B | 1.54 B | 1.88 C |
| Fine roots | 1.17 B | 0.64 C | 0.69 D |
| Subtotal (Permanent structure) | 10.36 | 10.01 | 11.58 |
| Total | 10.36 | 12.44 | 17.57 |
| LSD | 1.10 | 0.65 | 1.16 |
| Pr>F | <.0001 | <.0001 | <.0001 |

**Table 2:** The nitrogen content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees in a higher density (4.5m by 1.5m) orchard at three phenological stages.

a.)

| Tree part | N (g per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 11.14 CD | 31.13 B |
| Leaves | - | 52.08 A | 52.78 A |
| New shoots | - | 3.88 E | 6.80 C |
| Subtotal (new growth) | 0.00 | 67.10 | 90.71 |
| Bearing wood | 2.69 D | 2.64 E | 3.91 C |
| Scaffold branches | 3.98 D | 3.21 E | 4.94 C |
| Stem | 24.43 B | 22.86 B | 23.44 BC |
| Thick roots | 32.40 A | 16.49 BC | 22.41 BC |
| Fine roots | 17.15 C | 7.58 DE | 9.58 C |
| Subtotal (Permanent structure) | 80.65 | 52.78 | 64.28 |
| Total | 80.65 | 119.88 | 155.00 |
| LSD | 6.9477 | 6.9207 | 20.11 |
| Pr>F | <.0001 | <.0001 | 0.0012 |

b.)

| Tree part | N distribution (%) | | |
|---|---|---|---|
| | Winter | Pit hardening | Harvest |
| Fruit | - | 9.3 | 20.1 |
| Leaves | - | 43.4 | 34.1 |
| New shoots | - | 3.2 | 4.4 |
| Subtotal (new growth) | - | 56.0 | 58.5 |
| Bearing wood | 3.3 | 2.2 | 2.5 |
| Scaffold branches | 4.9 | 2.7 | 3.2 |
| Stem | 30.3 | 19.0 | 15.1 |
| Thick roots | 40.2 | 13.8 | 14.5 |
| Fine roots | 21.3 | 6.3 | 6.2 |
| Subtotal (Permanent structure) | 100.0 | 44.0 | 41.5 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 3:** The phosphorous content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees in a higher density (4.5m by 1.5m) orchard at three phenological stages.

a.)

| **Tree part** | **P (g per tree)** | | |
|---|---|---|---|
| | **Winter** | **Pip hardening** | **Harvest** |
| Fruit | - | 1.40 DC | 4.00 A |
| Leaves | - | 3.65 A | 2.92 AB |
| New shoots | - | 0.80 D | 1.20 CD |
| Subtotal (new growth) | 0.00 | 5.85 | 8.12 |
| Bearing wood | 0.26 C | 0.58 D | 0.76 D |
| Scaffold branches | 0.52 C | 0.62 D | 0.96 D |
| Stem | 2.01 B | 2.36 BC | 2.52 BC |
| Thick roots | 4.63 A | 2.81 AB | 3.92 A |
| Fine roots | 2.16 B | 1.16 D | 1.27 CD |
| Subtotal (Permanent structure) | 9.58 | 7.53 | 9.43 |
| Total | 9.58 | 13.38 | 17.55 |
| LSD | 0.8317 | 0.9675 | 1.3995 |
| Pr>F | <.0001 | <.0001 | 0.0003 |

b.)

| **Tree part** | **P (%)** | | |
|---|---|---|---|
| | **Winter** | **Pip hardening** | **Harvest** |
| Fruit | - | 10.4 | 22.8 |
| Leaves | - | 27.3 | 16.6 |
| New shoots | - | 6.0 | 6.8 |
| Subtotal (new growth) | - | 43.7 | 46.3 |
| Bearing wood | 2.7 | 4.4 | 4.3 |
| Scaffold branches | 5.4 | 4.6 | 5.5 |
| Stem | 21.0 | 17.7 | 14.4 |
| Thick roots | 48.3 | 21.0 | 22.4 |
| Fine roots | 22.5 | 8.7 | 7.2 |
| Subtotal (Permanent structure) | 100.0 | 56.3 | 53.7 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 4:** The potassium content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees in a higher density (4.5m by 1.5m) orchard at three phenological stages.

a.)

| Tree part | K (g per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 10.47 B | 54.59 A |
| Leaves | - | 46.98 A | 42.07 A |
| New shoots | - | 3.66 C | 5.48 B |
| Subtotal (new growth) | 0.00 | 61.11 | 102.14 |
| Bearing wood | 1.22 C | 2.12 C | 2.92 B |
| Scaffold branches | 1.52 BC | 1.84 C | 2.83 B |
| Stem | 9.45 A | 9.40 B | 11.07 B |
| Thick roots | 3.63 B | 2.89 C | 4.96 B |
| Fine roots | 3.67 B | 1.95 C | 2.23 B |
| Subtotal (Permanent structure) | 19.49 | 18.20 | 24.01 |
| Total | 19.49 | 79.32 | 126.14 |
| LSD | 2.1722 | 5.2323 | 15.289 |
| Pr>F | <.0001 | <.0001 | <.0001 |

b.)

| Tree part | K (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 13.2 | 43.3 |
| Leaves | - | 59.2 | 33.4 |
| New shoots | - | 4.6 | 4.3 |
| Subtotal (new growth) | - | 77.0 | 81.0 |
| Bearing wood | 6.3 | 2.7 | 2.3 |
| Scaffold branches | 7.8 | 2.3 | 2.3 |
| Stem | 48.5 | 11.9 | 8.8 |
| Thick roots | 18.6 | 3.6 | 3.9 |
| Fine roots | 18.8 | 2.5 | 1.7 |
| Subtotal (Permanent structure) | 100.0 | 23.0 | 19.0 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 5:** The calcium content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees in a higher density (4.5m by 1.5m) orchard at three phenological stages.

a.)

| Tree part | Ca (g per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 0.85 D | 1.58 C |
| Leaves | - | 18.94 A | 20.08 A |
| New shoots | - | 3.05 CD | 9.75 BC |
| Subtotal (new growth) | 0.00 | 22.84 | 31.41 |
| Bearing wood | 2.17 C | 2.40 CD | 4.86 BC |
| Scaffold branches | 4.38 B | 4.03 C | 7.60 BC |
| Stem | 8.84 A | 8.93 B | 9.05 BC |
| Thick roots | 3.34 BC | 3.00 CD | 3.96 BC |
| Fine roots | 1.68 C | 1.41 CD | 1.38 C |
| Subtotal (Permanent structure) | 20.41 | 19.77 | 26.85 |
| Total | 20.41 | 42.60 | 58.26 |
| LSD | 2.0212 | 2.8099 | 7.7219 |
| Pr>F | <.0001 | <.0001 | 0.0022 |

b.)

| Tree part | Ca (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 2.0 | 2.1 |
| Leaves | - | 44.5 | 34.5 |
| New shoots | - | 7.26 | 16.7 |
| Subtotal (new growth) | - | 53.6 | 53.9 |
| Bearing wood | 10.6 | 5.6 | 8.3 |
| Scaffold branches | 21.4 | 9.5 | 13.0 |
| Stem | 43.3 | 21.0 | 15.5 |
| Thick roots | 16.4 | 7.0 | 6.8 |
| Fine roots | 8.2 | 3.3 | 2.4 |
| Subtotal (Permanent structure) | 100.0 | 46.4 | 46.0 |
| Total | 100.00 | 100.0 | 100.0 |

**Table 6:** The magnesium content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees in a higher density (4.5m by 1.5m) orchard at three phenological stages.

a.)

| Tree part | Mg (g per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 0.70 C | 2.31 B |
| Leaves | - | 5.89 A | 5.89 A |
| New shoots | - | 0.53 C | 1.10 B |
| Subtotal (new growth) | | 7.12 | 9.30 |
| Bearing wood | 0.27 C | 0.32 C | 0.55 B |
| Scaffold branches | 0.50 C | 0.45 C | 0.85 B |
| Stem | 2.01 A | 2.41 B | 2.33 B |
| Thick roots | 1.28 B | 0.87 C | 1.08 B |
| Fine roots | 0.61 C | 0.41 C | 0.44 B |
| Subtotal (Permanent structure) | 4.67 | 4.46 | 5.25 |
| Total | 4.67 | 11.57 | 14.54 |
| LSD | 0.4125 | 0.6961 | 2.2775 |
| Pr>F | <.0001 | <.0001 | 0.0021 |

b.)

| Tree part | Mg (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 6.0 | 15.9 |
| Leaves | - | 50.9 | 40.5 |
| New shoots | - | 4.6 | 7.6 |
| Subtotal (new growth) | - | 61.5 | 64.0 |
| Bearing wood | 5.8 | 2.8 | 3.8 |
| Scaffold branches | 10.7 | 3.9 | 5.8 |
| Stem | 43.1 | 20.9 | 16.0 |
| Thick roots | 27.4 | 7.5 | 7.4 |
| Fine roots | 13.0 | 3.5 | 3.0 |
| Subtotal (Permanent structure) | 100.0 | 38.5 | 36.1 |
| Total | 100.0 | 100.0 | 100.0 |

## Addendum A

## Figures

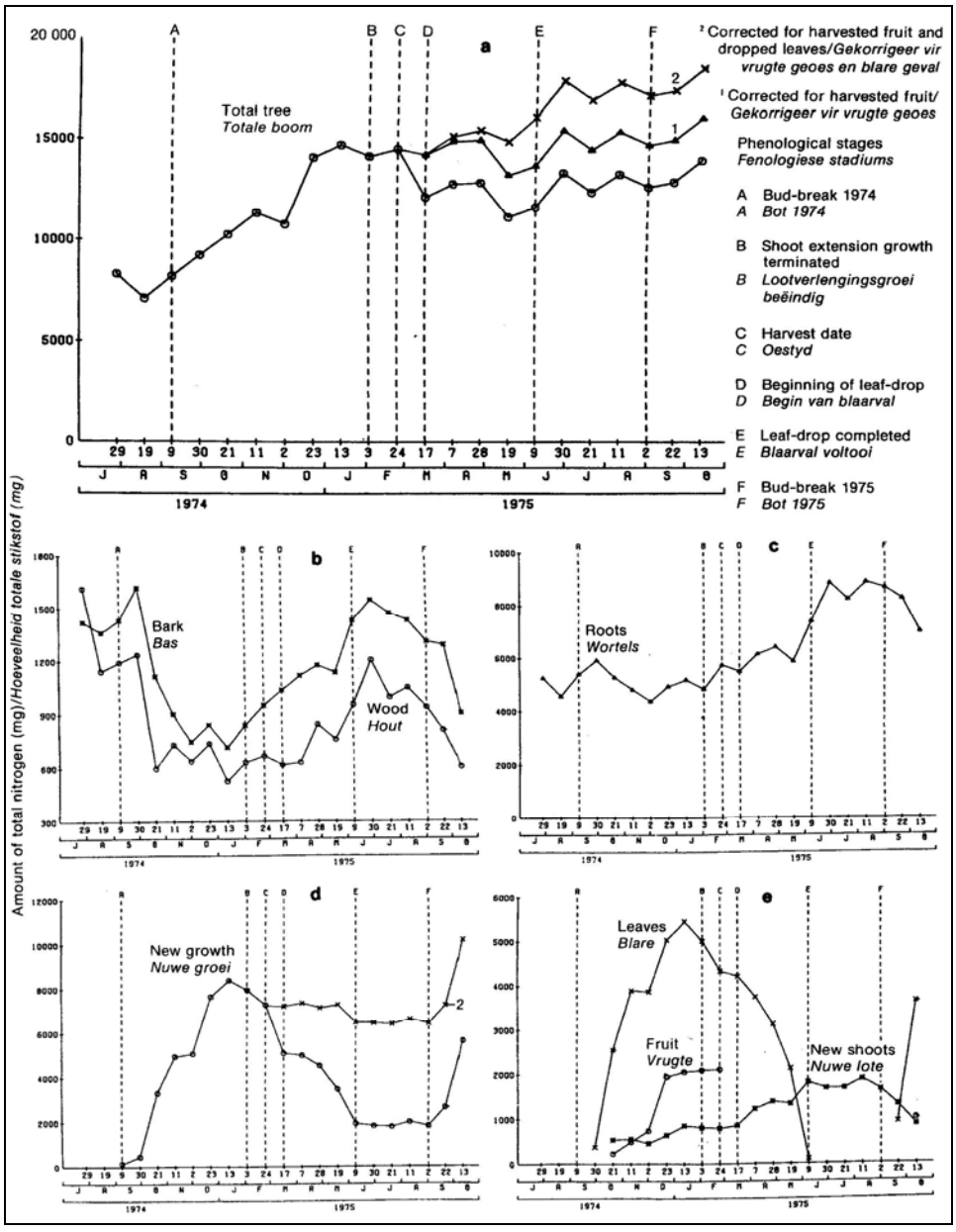


Figure 1: Seasonal changes in the amount of total nitrogen in two year old 'Kakamas' peach trees grown in sand culture (Stassen *et al.*, 1981a).

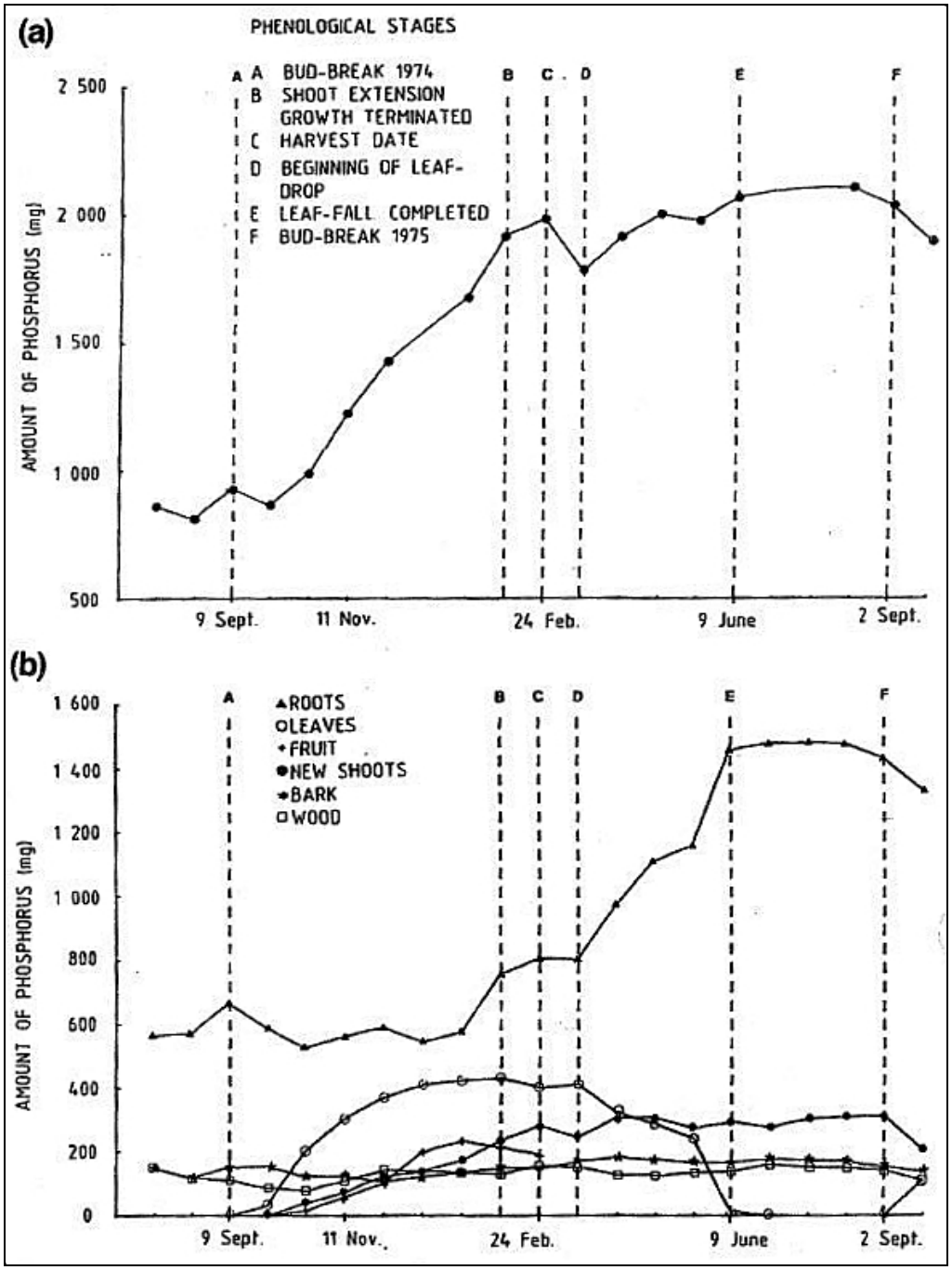


Figure 2: Seasonal changes in phosphorous content in two year old 'Kakamas' peach trees grown in sand culture for the whole tree (a) and different parts of the tree (b) (Stassen and Stadler, 1988).

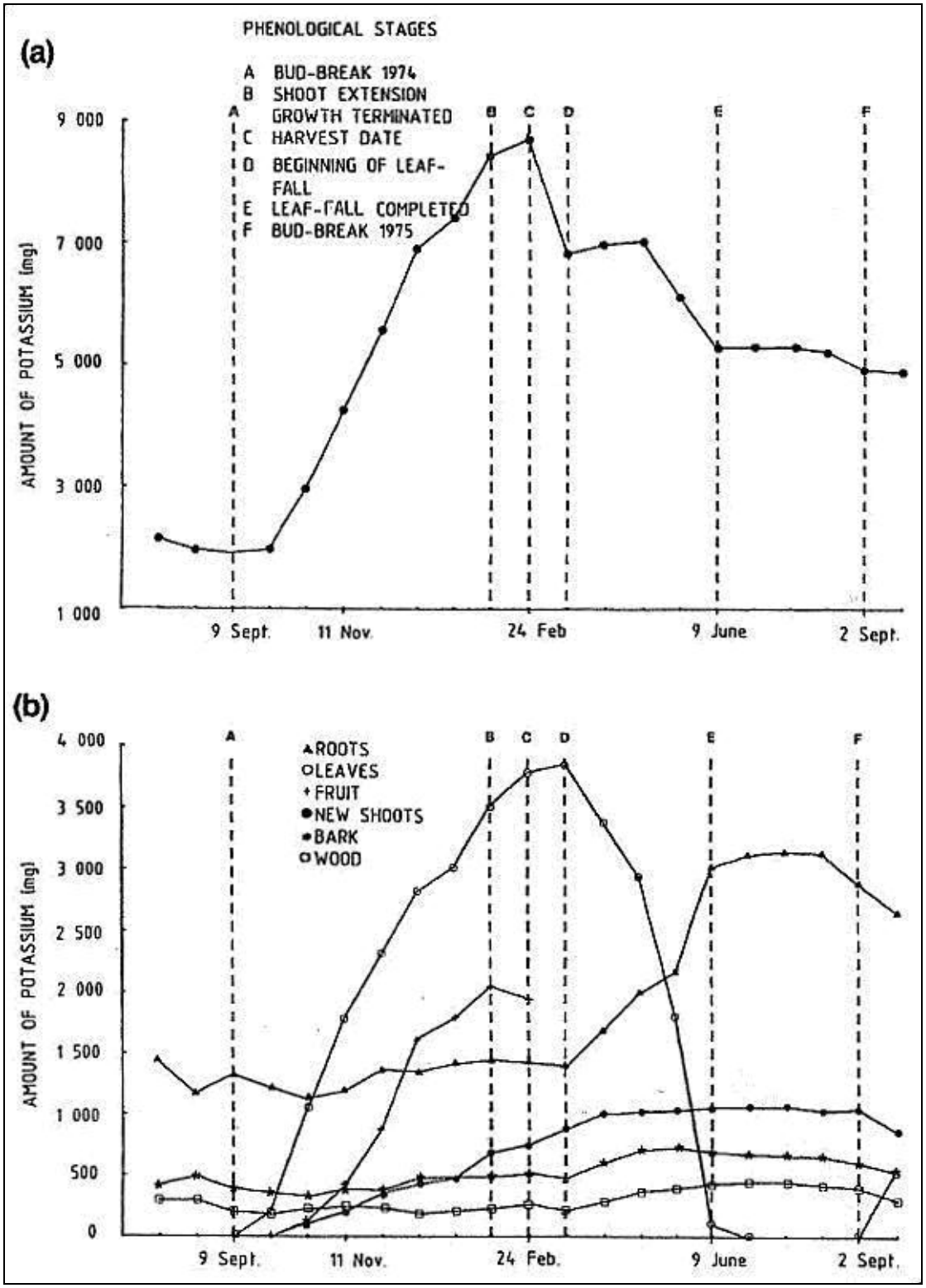


Figure 3: Seasonal changes in potassium content in two year old 'Kakamas' peach trees grown in sand culture for the whole tree (a) and different parts of the tree (b) (Stassen and Stadler, 1988).

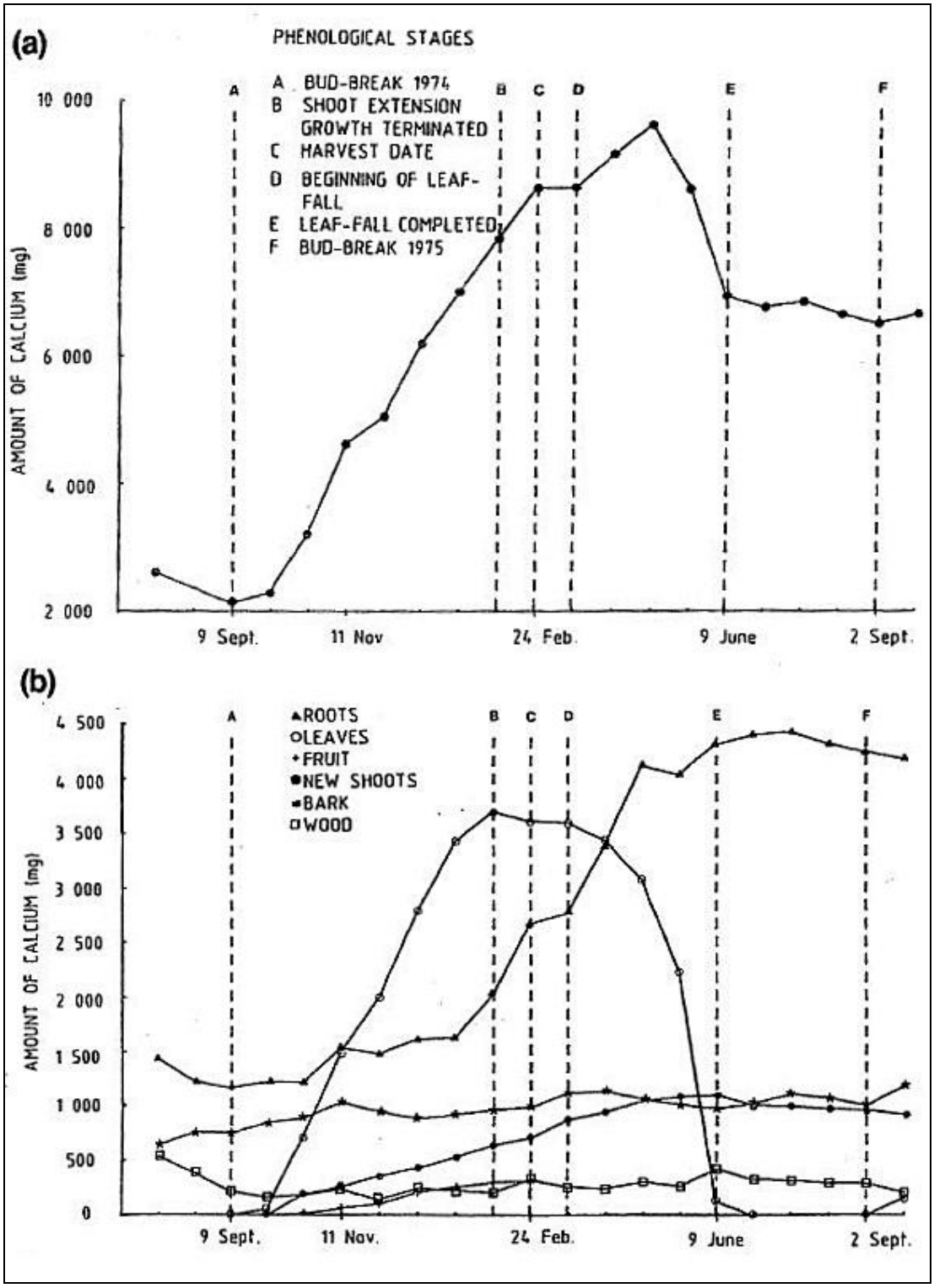


Figure 4: Seasonal changes in calcium content in two year old ‘Kakamas’ peach trees grown in sand culture for the whole tree (a) and different parts of the tree (b) (Stassen and Stadler, 1988).

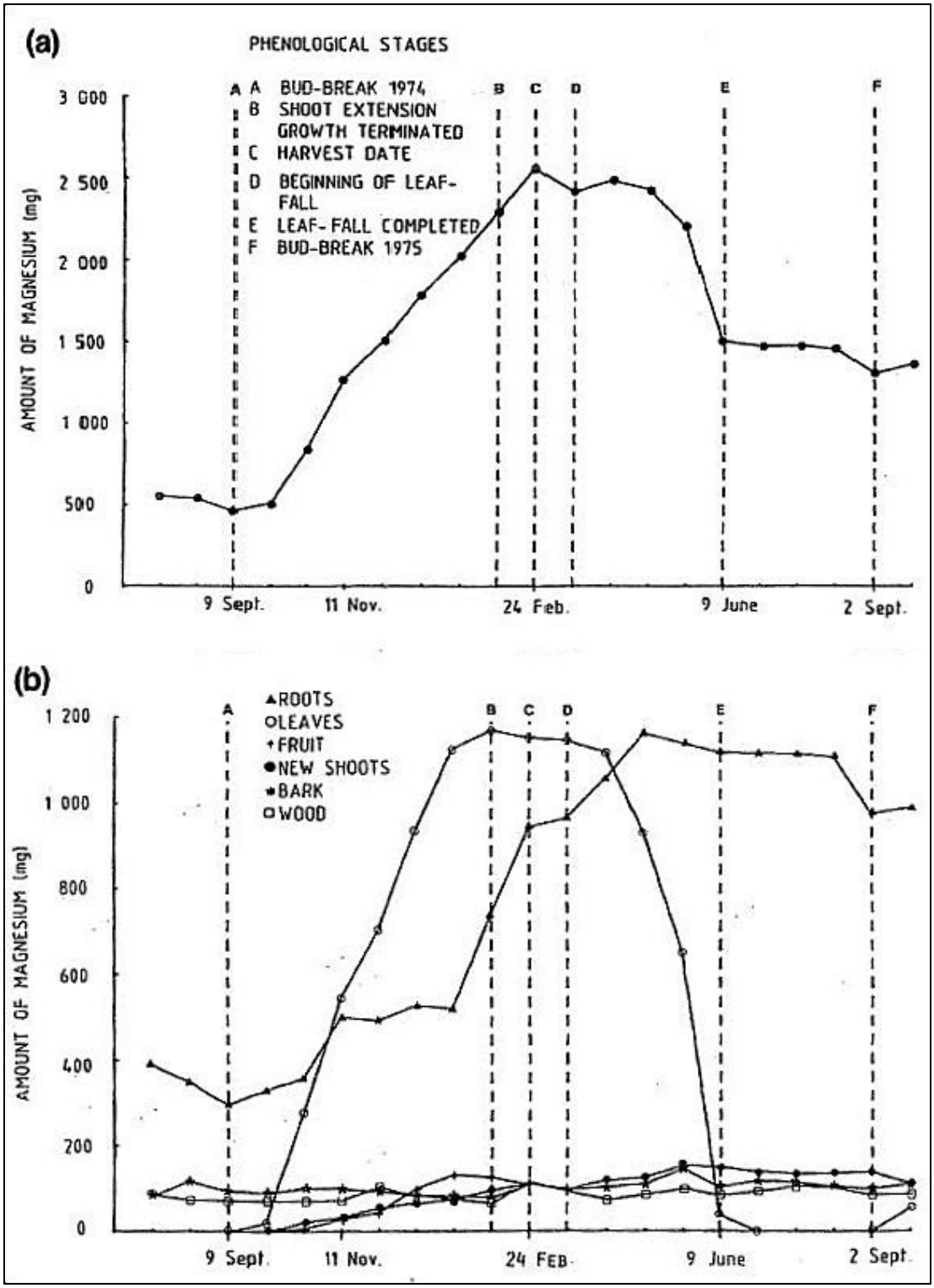


Figure 5: Seasonal changes in magnesium content in two year old ‘Kakamas’ peach trees grown in sand culture for the whole tree (a) and different parts of the tree (b) (Stassen and Stadler, 1988).

# CHAPTER 3

## Micro-element uptake and distribution by full bearing 'Donnarine' nectarines under pulsating drip fertigation.

### 3.1. Introduction

Mengel and Kirkby (1987) define nutrition as the supply and absorption of chemical compounds needed for growth and metabolism, and nutrients as the chemical compounds required by an organism. These chemical compounds can be split into macro- and micro-elements where the micro-elements B, Cl, Cu, Fe, Mn, Mo, Zn and Ni are required by plants in relatively small amounts (Gerendás *et al.*, 1999, Mengel and Kirkby, 1987; Van der Watt and Van Rooyen, 1995). This paper focuses on the uptake and distribution of the micro-elements Mn, Fe, Cu, Zn and B by full bearing 'Donnarine' nectarine trees. Even though sodium (Na) is not generally considered an essential element, it will be included in the discussion.

Micro-elements, while required in smaller amounts than the macro-elements (Marschner, 1986), still fulfill very important roles in the plant, as will be discussed here. While most of the iron in the plant is associated with chloroplasts, where it fulfils a role in chlorophyll synthesis, a small percentage forms complexes with proteins to form important enzymes in the plant (Scott Johnson and Uriru, 1998).

In the plant, manganese participates in several important processes including photosynthesis as well as nitrogen and carbohydrate metabolism (Scott Johnson and Uriru, 1998). Mn also activates a number of enzymes and has a role in the maintenance of the chloroplast membrane structure (Stassen *et al.*, 1999).

Trees require very small amounts of copper and more than half the copper in trees is located in the chloroplasts where it participates in photosynthetic reactions (Scott Johnson and Uriru, 1998). Copper has a role in chlorophyll synthesis and influences a number of metabolic reactions (Stassen *et al.*, 1999).

Although zinc is required in small amounts in the tree, it has been identified as a component of almost 60 enzymes. Zinc, therefore, fulfils a role in many plant functions, including functioning as an enzyme in the production of the growth hormone IAA (Scott Johnson and Uriru, 1998). Zn also acts as a catalyst in oxidation processes, is vital for the transformation of carbohydrates, plays a regulatory role in sugar consumption, has a role in the formation of growth promoting compounds and is important for photosynthesis (Stassen *et al.*, 1999).

Boron is involved in several processes in the plant, including protein synthesis, transport of sugars and the metabolism of plant hormones (Scott Johnson and Uriru, 1998). Furthermore boron plays an important role in germination, pollen tube growth, fertilization, cell division and the development of apical growing points (Stassen *et al.*, 1999).

While Mo is required in extremely small amounts, it has a role in nitrogen assimilation, is required for vitamin C synthesis, it enhances the uptake of N, K and Ca and plays a role in Fe absorption (Stassen *et al.*, 1999). No literature indicating that Na is essential to peach or nectarine trees could be found. Sodium is, however, essential to some higher plants (Brownell, 1968).

Little scientific data is available on the requirement and uptake of micro-elements by peach and nectarine trees. It is not known whether some micro nutrient play a role as reserve in nectarine trees. Terblanche (1972) included micro-elements in his studies on nutrient uptake and distribution by apples in sand culture. The objective of this trial was to study the micro-element uptake and distribution by higher density nectarine trees through the sequential excavation (Weinbaum *et al.*, 2001) of ‘Donnarine’ nectarine trees.

## 3.2. Materials and methods

The same ‘Donnarine’ nectarine trees as described in chapter two were used for the trial. The same methods were employed for the sequential excavation of the trees and the dried samples were subjected to mineral analysis for the micro-elements sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and boron (B) by a

commercial laboratory (BemLab Pty. Ltd, Somerset West, South Africa). The data was used to calculate the micro-element content of each part of each tree. Statistical analysis was conducted using SAS (Statistical Analysis System) statistical software (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, NC).

## 3.3. Results and discussion

### 3.3.1. Dry weight

Table 1 indicates the actual dry weight of the different tree parts in kg per tree during winter, at pip hardening and at harvest. The same trees as described in chapter 2 were used in this trial. Refer to section 2.3.1. in chapter two for the discussion of the data presented in table 1.

### 3.3.2. Sodium

Table 2a and 2b indicates the actual Na content of the different tree parts in mg per tree as well as the Na distribution in the tree during winter, at pip hardening and at harvest. In winter the total sodium (Na) content of the 'Donnarine' nectarine trees was 1038.31 mg per tree, located in the permanent structure (bearing wood, scaffold branches, stem and roots). Most (55.1%) of the Na was located in the stem, while the thick and fine roots respectively contained 20.4% and 10.0%; a combined total of 30.4% for the root sodium contribution. At this stage the branches contained 14.5% of the total Na, with the older scaffold branches containing 10.3% and the bearing wood contributing 4.2%.

As the season progressed from winter to pip hardening the total Na content increased to 1551.82 mg per tree at pip hardening through the uptake of 513.51 mg of Na per tree. At pip hardening 200.42 mg Na per tree was found in the new growth. This represents 39.0% of the Na taken up from winter to pip hardening. The remainder of the Na taken up from winter to pip hardening (313.09 mg per tree or 61.0%) was found in the permanent structure. Na was not stored as a reserve in the permanent structure of the nectarine trees during dormancy. At pip hardening the leaves contained 9.9% of the total Na and, while the stem Na contribution decreased from

55.1% to 43.3%, it still contained the most Na. The Na content of the stem increased with 100.52 mg per tree. The roots now contained 35.5% of the Na in the tree, representing a 5.1% increase in root contribution to total tree Na. The fruit contained 1.3% of the total Na at pip hardening.

From pip hardening to harvest the Na content increased by a further 485.17 mg per tree to 2036.99 mg per tree. The fruit contribution to the total Na content increased from 1.3% to 13.8%. $Na^+$ is known to have the ability to substitute $K^+$ (Mengel and Kirkby, 1987). The increase in the fruit contribution to total Na from pip hardening to harvest may be attributed to this fact (see chapter 2, section 2.3.4.). The actual Na content of the new growth (92.39 mg per tree) was almost 3.5 times more than at pip hardening (26.67 mg per tree). While the leaf Na contribution dropped from 9.9% to 8.9%, the actual Na content of the leaves actually increased by 27.36 mg per tree.

### 3.3.3. Manganese

Table 3a indicates the actual Mn content of the different tree parts in mg per tree during winter, at pip hardening and at harvest. Table 3b indicates the Mn distribution at the same stages. In winter the total Mn content of the 'Donnarine' nectarine trees was 96.31 mg per tree, located in the permanent structures. At this stage 41.8% of the Mn was located in the stem, while the thick and fine roots respectively contained 17.7% and 26.2%; a combined total of 43.9% for the root manganese contribution. The older scaffold branches contained 9.8% of the Mn and the bearing wood contained 4.7%; a total of 14.5% for the branches.

As the season progressed from winter to pip hardening the total Mn content increased to 139.14 mg per tree, representing uptake of 42.83 mg per tree. The permanent structure of the tree contained 59.60 mg of Mn per tree at pip hardening, representing a decrease of 36.71 mg per tree from winter. The total Mn in new growth (fruit, leaves and new shoots) was 79.53 mg per tree at this stage and the Mn uptake from winter to pip hardening was 42.83 mg per tree. This indicates that Mn plays a very important role as a reserve in the nectarine tree, with 46.2% or 36.71 mg of Mn per tree in the new growth coming from reserves translocated from the permanent structure of the tree. At pip hardening the leaves contained 48.1% of the total Mn, the stem

contributed 18.9%, the roots contributed 17.7% and the fruit contained 5.9% of the total Mn.

From pip hardening to harvest the Mn content increased by a further 117.16 mg per tree to 256.30 mg per tree. The fruit contribution to the total Mn content increased from 5.9% to 14.2%. All parts of the tree showed an increase in Mn content from pip hardening to harvest. The leaf Mn contribution dropped from 48.1% to 44.1% during this period, but the actual Mn content of the leaves increased substantially, by 46.18 mg per tree. During the same period the Mn content of the permanent structure of the tree increased by 32.46 mg per tree to 92.06 mg per tree.

### 3.3.4. Iron

Table 4a and 4b indicates the actual Fe content of the different tree parts in mg per tree as well as the Fe distribution in the tree during winter, at pip hardening and at harvest. In winter the total Fe content of the 'Donnarine' nectarine trees was 813.80 mg per tree, located in the permanent structure (bearing wood, scaffold branches, stem and roots). The stem contained 55.8% of the Fe while the thick and fine roots respectively contained 16.7% and 20.7%; a combined total of 37.4% for the root iron contribution. At this stage 5.1% of the Fe was found in the older scaffold branches and 1.8% in the bearing wood, a total of 6.9% for the branches.

As the season progressed from winter to pip hardening 166.38 mg of Fe per tree was taken up, increasing the total Fe content to 980.18 mg per tree. The permanent structure of the tree contained 569.00 mg of Fe per tree at pip hardening, representing a decrease of 244.80 mg per tree from winter. The total Fe in new growth (fruit, leaves and new shoots) was 411.18 mg per tree at this stage. This indicates that Fe acts as a reserve in the tree, with 59.5% or 244.80 mg of Fe per tree in the new growth coming from reserves translocated from the permanent structure of the tree. The stem Fe contribution decreased from 55.8% to 18.4% from winter to pip hardening. The roots contained 31.6% of the Fe in the tree at pip hardening, a 5.8% decrease from winter. This indicates that the stem played a more important role in the storage of Fe as reserves than the roots. At pip hardening the leaves contained 22.6% of the total Fe. At the same stage the fruit contributed 16.4% to the total Fe.

From pip hardening to harvest the Fe content increased by a further 377.12 mg per tree to 1357.30 mg per tree. The fruit contribution to the total Fe content decreased from 16.4% to 11.4%. The actual Fe content of the fruit, however, was only slightly (6.71 mg per tree) less at harvest than at pip hardening. All the Fe in the fruit itself was therefore absorbed between winter and pip hardening. The leaf Fe contribution increased from 22.6% to 30.9%. This was due to a 197.24 milligram per tree increase in leaf Fe content, from 221.84 mg per tree at pip hardening to 419.08 mg per tree at harvest. During the same period the Fe content of the permanent structure of the tree increased by 163.03 mg per tree to 732.03 mg per tree.

### 3.3.5. Copper

Table 5a indicates the actual Cu content of the different tree parts in mg per tree during winter, at pip hardening and at harvest. Table 5b indicates the Cu distribution at the same stages. In winter the total Cu content of the 'Donnarine' nectarine trees was 293.85 mg per tree, located in the permanent structure. The stem contained 50.9% of the Cu, while the thick and fine roots respectively contained 2.4% and 3.4%; a combined total of 5.8% for the root Cu contribution. At this stage 26.9% of the Cu was found in the older scaffold branches and 16.4% in the bearing wood; a total of 43.3% for the branches.

As the season progressed from winter to pip hardening the total Cu content did not increase, but the distribution of Cu in the tree changed. The leaves now contained 7.6% of the Cu, while the stem Cu contribution dropped only slightly from 50.9% to 50.1%. The roots now contained 5.7% of the Cu in the tree; very similar to winter. The fruit contained 2.2% of the total Cu at pip hardening.

At harvest the copper content of the trees was slightly higher, at 286.99 g per tree, than at pip hardening. The leaves now contained 5.1% of the Cu and while the stem Cu contribution decreased only slightly from 50.1 to 45.2%. At harvest roots contained 4.9% of the Cu in the tree which was marginally less than at pip hardening. The fruit contained 3.4% of the total Cu at harvest.

### 3.3.6. Zinc

Table 6a and 6b indicates the actual Zn content of the different tree parts in mg per tree, and the Zn distribution in the tree during winter, at pip hardening and at harvest. In winter the total Zn content of the 'Donnarine' nectarine trees was 428.25 mg per tree, located in the permanent structure. The stem contained 49.7% of the Zn while the thick and fine roots respectively contained 17.2% and 13.3%; a combined total of 30.5% for the root zinc contribution. The older scaffold branches contained 14.6% of the Zn and the bearing wood contributed 5.2%; a total of 19.8%.

From winter to pip hardening the total Zn content increased to 663.79 mg per tree at pip hardening through the uptake of 235.54 mg of Zn per tree. The permanent structure of the tree contained 400.57 mg of Zn per tree at pip hardening, representing a decrease of 27.68 mg per tree from winter. The total Zn in new growth (fruit, leaves and new shoots) was 263.22 mg per tree at this stage and this indicates that 10.5% or 27.68 mg of Zn per tree in the new growth come from reserves originating in the permanent structure of the tree. At pip hardening the leaves contained 31.6% of the Zn, the fruit contributed 3.3% and the stem Zn contribution was 33.9%. The roots now contained 12.7% of the Zn in the tree; a 17.9% decrease from winter. The roots played the most important role as storage organs for Zn reserves during dormancy.

From pip hardening to harvest the Zn content increased by a further 109.29 mg per tree to 773.08 mg per tree. At the same time the Zn content of the permanent structure increased by 92.77 mg per tree to a level of 493.34 mg per tree. The fruit contribution to the total Zn content increased from 3.3% to 4.7%. During the same period the leaf Zn contribution decreased from 31.6% to 19.0%. This indicates that some Zn was translocated from the leaves to other parts of the tree during the period between pip hardening and harvest.

### 3.3.7. Boron

Table 7a indicates the actual B content of the different tree parts in mg per tree during winter, at pip hardening and at harvest. Table 7b indicates the B distribution at the same stages. In winter the total B content of the 'Donnarine' nectarine trees was 78.43

mg per tree, located in the permanent structure of the tree. The stem contained 56.6% of the B while the thick and fine roots respectively contained 15.5% and 15.2%; a combined total of 30.7% for the root boron contribution. During winter 8.5% of the B was found in the older scaffold branches and 4.2% in the bearing wood; a total of 12.7% for the branches.

As the season progressed from winter to pip hardening uptake of 89.69 mg B per tree increased the total B content to 168.12 mg per tree. The permanent structure of the tree contained 73.80 mg of B per tree at pip hardening, representing a decrease of 4.63 mg per tree from winter. The total B in new growth (fruit, leaves and new shoots) was 94.33 mg per tree at pip hardening. Taking into account that the B uptake from winter to pip hardening was 89.69 mg per tree, this indicates that 4.9% or 4.63 mg of B per tree in the new growth came from reserves translocated from the permanent structure of the tree. At pip hardening the leaf contribution to total B content was 37.4% and the fruit contained 13.9% of the total B. The stem B contribution decreased from 56.6% to 23.5% from winter to pip hardening and the roots now contained 12.7% of the B in the tree; an 18.0% decrease from winter.

From pip hardening to harvest the B content increased by a further 123.89 mg per tree to 292.01 mg per tree. During the same period the B content of the permanent structure increased by 15.56 mg per tree to 89.36 mg per tree. The fruit contribution to the total B content increased from 13.9% to 44.4%. The actual B content of the fruit was approximately 5.5 times higher at harvest than at pip hardening. Fruit was the strongest sink for B during this period. The leaf B contribution dropped from 37.4% to 19.9%, the actual B content of the leaves was 4.98 mg per tree less than at pip hardening.

### 3.4. Conclusion

Data indicated that Mn acts as a reserve in the tree, with 46.2% of Mn found in the new growth (fruit, leaves and new shoots) at pip hardening, coming from reserves translocated from the permanent structure of the tree. This has important implications due to the fact that Mn participates in several important processes in the tree, including photosynthesis (Scott Johnson and Uriru, 1998), and has a role in the

maintenance of the chloroplast membrane structure (Stassen *et al.*, 1999). Trees must therefore have adequate stores of Mn in the permanent structure prior to the onset of the growing season.

Iron also acts as a reserve in the tree, with 59.5% of Fe found in the new growth (fruit, leaves and new shoots) at pip hardening, coming from reserves translocated from the permanent structure of the tree. Similarly to Mn, Fe is also associated with the chloroplast where it fulfils a role in chlorophyll synthesis (Scott Johnson and Uriru, 1998). It is therefore, as in the case of Mn, important that the tree contains adequate Fe reserves at the start of the growing season.

Of the Zn found in the new growth (fruit, leaves and new shoots) at pip hardening, 10.5% came from reserves translocated from the permanent structure of the tree. This indicates that Zn has a role as reserve in the nectarine tree, but to a lesser extent than Mn and Fe.

During this trial 4.9% of boron found in the new growth at pip hardening represented B reserves translocated from the permanent structure. This is not a large percentage, but still indicates that B reserves play a small role in the nectarine tree. Sodium is not commonly considered an essential micro-element and previous work on the sodium requirement of peaches and nectarines could not be found. According to findings in the current trial sodium did not act as a reserve in the nectarine trees.

Previous work on the uptake and distribution of micro-elements by nectarine or peach trees could not be found. The data from the current trial is therefore valuable in indicating whether micro-elements also, like some macro-elements, play a role as reserves in the tree. Mn, Fe and to a lesser extent Zn and B did act as reserves in the permanent structure of nectarine trees. It is very important that trees do not start a new growing season with a deficiency in these elements. Annual mineral analysis of leaf samples must be performed to quantify the nutritional status of the orchard. If deficiencies in the above mentioned elements, especially Fe and Mn, are prevalent, it must be taken into account during the compilation of mineral nutrition program.

According to studies conducted by Terblanche (1972) on apples, Fe, Mn and Zn does not move back to the permanent structure of the tree before leaf drop and 66% of leaf B content is lost when the leaves fall. This indicates that, of the above mentioned elements, only B deficiency can be effectively treated through post harvest foliar sprays. Future research should be conducted to determine whether all Fe, Mn and Zn are lost through leaf fall in nectarines, as is the case for apples.

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## Tables

**Table 1:** The dry weight (kg) of full bearing 'Donnarine' nectarine trees in a higher density (4.5m by 1.5m) orchard at three phenological stages.

| Tree part | Dry weight (kg per tree) | | |
|---|---|---|---|
| | **Winter** | **Pip hardening** | **Harvest** |
| Fruit | - | 0.70 C | 3.63 B |
| Leaves | - | 1.40 B | 1.59 CD |
| New shoots | - | 0.34 C | 0.76 CD |
| Subtotal (new growth) | - | 2.43 | 5.98 |
| Bearing wood | 0.22 C | 0.40 C | 0.78 CD |
| Scaffold branches | 0.77 C | 0.75 C | 1.41 CD |
| Stem | 6.07 A | 6.68 A | 6.82 A |
| Thick roots | 2.13 B | 1.54 B | 1.88 C |
| Fine roots | 1.17 B | 0.64 C | 0.69 D |
| Subtotal (Permanent structure) | 10.36 | 10.01 | 11.58 |
| Total | 10.36 | 12.44 | 17.57 |
| LSD | 1.10 | 0.65 | 1.16 |
| Pr>F | <.0001 | <.0001 | <.0001 |

**Table 2:** The sodium content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees, in a higher density (4.5m by 1.5m) orchard, at three phenological stages.

a.)

| Tree part | Na content (mg per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 20.71 E | 280.72 BC |
| Leaves | - | 153.04 C | 180.40 BCD |
| New shoots | - | 26.67 E | 92.39 D |
| Subtotal (new growth) | 0.00 | 200.42 | 553.51 |
| Bearing wood | 43.45 C | 42.67 DE | 79.58 D |
| Scaffold branches | 107.39 BC | 85.75 D | 178.09 BCD |
| Stem | 571.75 A | 672.27 A | 757.70 A |
| Thick roots | 211.85 B | 351.88 B | 320.60 B |
| Fine roots | 103.87 BC | 198.83 C | 147.51 CD |
| Subtotal (Permanent structure) | 1038.31 | 1351.4 | 1483.48 |
| Total | 1038.31 | 1551.82 | 2036.99 |
| LSD | 146.69 | 50.056 | 166.91 |
| Pr>F | <.0001 | <.0001 | <.0001 |

b.)

| Tree part | Na distribution (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 1.3 | 13.8 |
| Leaves | - | 9.9 | 8.9 |
| New shoots | - | 1.7 | 4.5 |
| Subtotal (new growth) | - | 12.9 | 27.2 |
| Bearing wood | 4.2 | 2.8 | 3.9 |
| Scaffold branches | 10.3 | 5.5 | 8.7 |
| Stem | 55.1 | 43.3 | 37.2 |
| Thick roots | 20.4 | 22.7 | 15.7 |
| Fine roots | 10.0 | 12.8 | 7.2 |
| Subtotal (Permanent structure) | 100.0 | 87.1 | 72.8 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 3:** The manganese content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees, in a higher density (4.5m by 1.5m) orchard, at three phenological stages.

a.)

| Tree part | Mn content (mg per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 8.14 CD | 36.47 B |
| Leaves | - | 66.88 A | 113.06 A |
| New shoots | - | 4.51 CD | 14.71 B |
| Subtotal (new growth) | 0.00 | 79.53 | 164.24 |
| Bearing wood | 4.51 C | 3.21 D | 10.00 B |
| Scaffold branches | 9.39 C | 5.50 CD | 13.57 B |
| Stem | 40.22 A | 26.22 B | 36.91 B |
| Thick roots | 17.00 BC | 10.25 CD | 16.66 B |
| Fine roots | 25.18 B | 14.42 C | 14.92 B |
| Subtotal (Permanent structure) | 96.31 | 59.60 | 92.06 |
| Total | 96.31 | 139.14 | 256.30 |
| LSD | 13.825 | 9.9204 | 41.6 |
| Pr>F | 0.0014 | <.0001 | 0.0013 |

b.)

| Tree part | Mn distribution (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 5.9 | 14.2 |
| Leaves | - | 48.1 | 44.1 |
| New shoots | - | 3.2 | 5.7 |
| Subtotal (new growth) | - | 57.2 | 64.1 |
| Bearing wood | 4.7 | 2.3 | 3.9 |
| Scaffold branches | 9.8 | 4.0 | 5.3 |
| Stem | 41.8 | 18.9 | 14.4 |
| Thick roots | 17.7 | 7.4 | 6.5 |
| Fine roots | 26.2 | 10.4 | 5.8 |
| Subtotal (Permanent structure) | 100.0 | 42.8 | 35.9 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 4:** The iron content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees, in a higher density (4.5m by 1.5m) orchard, at three phenological stages.

a.)

| Tree part | Fe (mg per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 161.18 ABC | 154.47 B |
| Leaves | - | 221.84 A | 419.08 A |
| New shoots | - | 28.16 C | 51.72 B |
| Subtotal (new growth) | 0.00 | 411.18 | 625.27 |
| Bearing wood | 14.80 B | 30.98 C | 49.36 B |
| Scaffold branches | 41.10 B | 48.00 BC | 73.85 B |
| Stem | 454.00 A | 180.60 AB | 182.52 B |
| Thick roots | 135.60 AB | 116.34 ABC | 197.02 B |
| Fine roots | 168.30 AB | 193.08 A | 229.28 B |
| Subtotal (Permanent structure) | 813.80 | 569.00 | 732.03 |
| Total | 813.80 | 980.18 | 1357.30 |
| LSD | 332.52 | 137.19 | 189.17 |
| Pr>F | 0.0889 | 0.0366 | 0.0136 |

b.)

| Tree part | Fe (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 16.4 | 11.4 |
| Leaves | - | 22.6 | 30.9 |
| New shoots | - | 2.9 | 3.8 |
| Subtotal (new growth) | - | 41.9 | 46.1 |
| Bearing wood | 1.8 | 3.2 | 3.6 |
| Scaffold branches | 5.1 | 4.9 | 5.4 |
| Stem | 55.8 | 18.4 | 13.5 |
| Thick roots | 16.7 | 11.9 | 14.5 |
| Fine roots | 20.7 | 19.7 | 16.9 |
| Subtotal (Permanent structure) | 100.0 | 58.1 | 53.9 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 5:** The copper content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees, in a higher density (4.5m by 1.5m) orchard, at three phenological stages.

a.)

| Tree part | Cu (mg per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 5.57 C | 9.81 C |
| Leaves | - | 18.93 C | 14.69 C |
| New shoots | - | 3.14 C | 4.42 C |
| Subtotal (new growth) | 0.00 | 27.64 | 28.92 |
| Bearing wood | 48.25 BC | 20.32 C | 27.71 C |
| Scaffold branches | 78.96 B | 62.54 B | 86.67 B |
| Stem | 149.64 A | 125.27 A | 129.75 A |
| Thick roots | 7.11 C | 7.44 C | 7.52 C |
| Fine roots | 9.89 C | 6.94 C | 6.42 C |
| Subtotal (Permanent structure) | 293.85 | 222.51 | 258.07 |
| Total | 293.85 | 250.15 | 286.99 |
| LSD | 49.736 | 40.763 | 34.722 |
| Pr>F | 0.0004 | <.0001 | <.0001 |

b.)

| Tree part | Cu (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 2.2 | 3.4 |
| Leaves | - | 7.6 | 5.1 |
| New shoots | - | 1.3 | 1.5 |
| Subtotal (new growth) | 0.0 | 11.1 | 10.1 |
| Bearing wood | 16.4 | 8.1 | 9.7 |
| Scaffold branches | 26.9 | 25.0 | 30.2 |
| Stem | 50.9 | 50.1 | 45.2 |
| Thick roots | 2.4 | 3.0 | 2.6 |
| Fine roots | 3.4 | 2.8 | 2.2 |
| Subtotal (Permanent structure) | 100.0 | 88.9 | 89.9 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 6:** The zinc content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees, in a higher density (4.5m by 1.5m) orchard, at three phenological stages.

a.)

| Tree part | Zn (mg per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 22.07 C | 36.45 C |
| Leaves | - | 209.56 A | 146.97 AB |
| New shoots | - | 31.59 BC | 96.32 BC |
| Subtotal (new growth) | 0.00 | 263.22 | 279.74 |
| Bearing wood | 22.14 C | 33.93 BC | 83.26 BC |
| Scaffold branches | 62.39 B | 57.91 B | 109.94 BC |
| Stem | 212.94 A | 224.69 A | 194.73 A |
| Thick roots | 73.64 B | 43.06 BC | 64.08 C |
| Fine roots | 57.14 B | 40.98 BC | 41.33 C |
| Subtotal (Permanent structure) | 428.25 | 400.57 | 493.34 |
| Total | 428.25 | 663.79 | 773.08 |
| LSD | 32.592 | 35.717 | 74.515 |
| Pr>F | <.0001 | <.0001 | 0.005 |

b.)

| Tree part | Zn (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 3.3 | 4.7 |
| Leaves | - | 31.6 | 19.0 |
| New shoots | - | 4.8 | 12.5 |
| Subtotal (new growth) | - | 39.7 | 36.2 |
| Bearing wood | | 5.1 | 10.8 |
| Scaffold branches | 14.6 | 8.7 | 14.2 |
| Stem | 49.7 | 33.9 | 25.2 |
| Thick roots | 17.2 | 6.5 | 8.3 |
| Fine roots | 13.3 | 6.2 | 5.4 |
| Subtotal (Permanent structure) | 100.0 | 60.4 | 63.8 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 7:** The boron content (a) and distribution (b) of full bearing 'Donnarine' nectarine trees, in a higher density (4.5m by 1.5m) orchard, at three phenological stages.

a.)

| Tree part | B (mg per tree) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 23.39 C | 129.72 A |
| Leaves | - | 62.93 A | 57.95 B |
| New shoots | - | 8.01 DE | 14.98 D |
| Subtotal (new growth) | 0.00 | 94.33 | 202.65 |
| Bearing wood | 3.30 C | 5.34 E | 9.71 D |
| Scaffold branches | 6.69 BC | 7.68 DE | 13.41 D |
| Stem | 44.38 A | 39.48 B | 39.04 BC |
| Thick roots | 12.14 B | 13.88 D | 19.59 CD |
| Fine roots | 11.92 B | 7.42 DE | 7.61 D |
| Subtotal (Permanent structure) | 78.43 | 73.80 | 89.36 |
| Total | 78.43 | 168.12 | 292.01 |
| LSD | 8.228 | 8.0932 | 22.981 |
| Pr>F | <.0001 | <.0001 | <.0001 |

b.)

| Tree part | B (%) | | |
|---|---|---|---|
| | Winter | Pip hardening | Harvest |
| Fruit | - | 13.9 | 44.4 |
| Leaves | - | 37.4 | 19.9 |
| New shoots | - | 4.8 | 5.1 |
| Subtotal (new growth) | - | 56.1 | 69.4 |
| Bearing wood | 4.2 | 3.2 | 3.3 |
| Scaffold branches | 8.5 | 4.6 | 4.6 |
| Stem | 56.6 | 23.5 | 13.4 |
| Thick roots | 15.5 | 8.3 | 6.7 |
| Fine roots | 15.2 | 4.4 | 2.6 |
| Subtotal (Permanent structure) | 100.0 | 43.9 | 30.6 |
| Total | 100.0 | 100.0 | 100.0 |

# CHAPTER 4

## Mineral nutrient requirement guidelines for full bearing higher density nectarines (cv. Donnarine) grown under pulsating drip fertigation.

### 4.1. Introduction

Accurate water and fertilizer management is essential in highly intensive orchard systems to enable the manipulation of both reproductive and vegetative development, to ensure the possibility of higher quality fruit, with longer storage potential, and to reduce pollution and costs (Tagliavini and Marangoni, 2000). Where factors in the orchard negatively influence the uptake of nutrients by the tree, one should firstly make an attempt to alleviate or eliminate such factors detrimental to nutrient uptake before applying more than the required amount of nutrients, as this may lead to nutrient imbalances, excessive fertilizing and contamination of water sources.

Research plays an important role in empowering producers to make the correct decisions regarding the mineral nutrition of their fruit trees. Guidelines regarding the elemental requirements for optimum growth, production and fruit quality per fruit kind and cultivar, especially under higher planting densities, need to be determined (Stassen and North, 2005).

Weinbaum *et al.* (2001) emphasized that the sequential excavation of trees coupled with biomass determinations and nutrient analysis is the only research method that can reliably indicate the amounts and seasonal patterns of tree nutrient uptake. Many such nutritional studies have been conducted for a variety of crops. Peach trees (Stassen *et al.*, 1981a; Stassen *et al.*, 1981b; Stassen *et al.*, 1983; Stassen, 1987), apple trees (Batjer *et al.*,1952; Terblanche, 1972; Haynes and Goh, 1980), mango trees (Stassen *et al.*, 1997a; 1997b), avocado trees (Stassen *et al.*, 1997c), grapevines (Conradie, 1980; Conradie, 1981), pear trees (Stassen and North, 2005) and pistachio trees (Rosecrance *et al.*, 1996) were all investigated.

The previous work done on peach trees (Stassen *et al.*, 1981a; Stassen *et al.*, 1981b; Stassen *et al.*, 1983; Stassen, 1987) made use of large, widely spaced trees or trees

grown in sand culture. Many modern South African nectarine orchards are established at relatively high densities and pruned and trained as central leader, slender spindle or two-leader V-system trees. Due to the differences in tree architecture, one expects differences in the mineral nutrient demand, when comparing these smaller trees to the large trees of the past. The objective of this trial was to determine the mineral nutrient demand of higher density nectarine trees through the sequential excavation of trees and calculation of losses and fixation.

## 4.2. Materials and methods

The same 'Donnarine' nectarine trees as described in chapter two were used for the trial. The same methods were employed for the sequential excavation of the trees as described in that chapter. In addition to the tree parts mentioned in chapter one, the cuttings removed from the trees during summer and winter pruning were included in the analysis. The trunk circumference of the trees was measured at each excavation date. Two years after the start of the trial the trunk circumferences of twenty five randomly selected trees in the same commercial orchard were measured. This was done in order to get an indication of the dry mass increase of the trees, based on trunk circumference.

Dried samples were subjected to mineral analysis for N, P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn and B by a commercial laboratory (BemLab Pty. Ltd, Somerset West, South Africa). The data was used to calculate the macro -and micro-element content of each part of each tree. Nutrient losses through fruit, leaves and prunings, as well as fixation in the permanent structure, were calculated and related to the loss per hectare to produce one ton of fruit. The yield was 25 tons per hectare and the trees are full bearing. Statistical analysis was conducted using SAS (Statistical Analysis System) statistical software (SAS Enterprise Guide 3.0, SAS Institute, 2004, Cary, NC).

## 4.3. Results

Previous work showed that 50% of nitrogen from the leaves at harvest is translocated to the permanent structure before leaf drop (Stassen *et al.*, 1981a). Whereas, approximately 30% of phosphorous, 40% of potassium, 60% copper and 66% of

boron is lost through leaf drop (Terblanche, 1972). Calcium, magnesium, manganese, iron and zinc does not move back to the permanent structure of the tree before leaf drop (Terblanche, 1972). Literature indicating whether sodium migrates back from the leaves to the permanent structure of the tree before leaf drop could not be found. For the purpose of this study we accept a 100% loss of Ca, Mg, Mn, Fe, Zn and Na from the leaves during leaf drop. Therefore, for each tree, 26.39 g of N, 0.88 g of P, 16.83 g of K, 20.08 g of Ca, 5.89 g of Mg, 180.40 mg of Na, 113.06 mg of Mn, 419.08 mg of Fe, 8.81 mg of Cu, 146.97 mg of Zn and 38.25 mg of B was lost from the tree through leaf fall.

Furthermore, each tree lost 3.39 g of N, 0.54 g of P, 2.48 g of K, 3.30 g of Ca, 0.44 g of Mg, 40.79 mg of Na, 5.49 mg of Mn, 22.76 mg of Fe, 23.14 mg of Cu, 6.13 mg of Zn and 6.13 mg of B through summer and winter pruning. The fruit removed during harvest accounted for losses of 31.13 g of N, 4.00 g of P, 54.59 g of K, 1.58 g of Ca, 2.31 g of Mg, 280.72 mg of Na, 36.47 mg of Mn, 154.47 mg of Fe, 9.81 mg of Cu, 36.45 mg of Zn and 129.72 mg of B from each tree.

The data given above represents the nutrient losses per tree through leaf fall, pruning and crop removal. From this data the nutrient requirement per hectare to produce one ton of fruit at a yield of 25 tons per hectare, was calculated. Stassen (1987), in his paper on the macro-element content and distribution in peach trees, gave the annual mineral nutrient requirements of peach trees as the amount of nutrients required to produce one kg of fruit. In the same way, table 1a and 1b contains the amount of macro-nutrients in kg, and micronutrients in g, required to produce one ton of fruit.

In addition to the annual amount of nutrients removed through leaf fall, pruning and crop removal, fixation in the permanent structure of the tree also renders an amount of nutrients inaccessible to the plant (Stassen, 1987). Stassen *et al.* (2000) found that a highly significant correlation exists between trunk circumference, total tree dry mass, tree canopy volume and fruit yield of mango trees. The relative increase in trunk circumference can be related to the relative increase in total tree dry mass (Stassen *et al.*, 2000.) This information is useful in estimating the annual loss of nutrient to fixation in the permanent structure. The trunk circumference of the trees in the trial orchard increased by 8.79% over the 24 month period since the trial commenced. A

4.40% annual increase was used to calculate the nutrient levels the permanent structure should contain during dormancy, prior to the next growing season, and fixation in the permanent structure of the tree was therefore taken into account. The amount of nutrients lost through fixation into the permanent structure of the tree is given in table 1a and 1b for macro-nutrients in kg and micronutrients in g required to produce one ton of fruit.

## 4.4. Discussion

Guideline requirements per ton of fruit produced per hectare by higher density nectarine orchards are respectively 3.82kg N, 0.35kg P, 4.43kg K, 1.53kg Ca, 0.52kg Mg, 32.45g Na, 9.44g Mn, 37.46g Fe, 3.24g Cu, 13.95g Zn and 10.52g B. These annual guidelines were determined through calculation of losses and fixation and are given in table 1a and 1b.

The annual amount of nitrogen required to produce one ton of fruit was found to be 3.82kg. This is lower than the 5.6g of nitrogen to produce 1kg of fruit that Stassen (1987) found for large ten year old ‘Kakamas’ peach trees, but is very close to the 4.0kg of nitrogen to produce one ton of peaches that Stassen (2001) proposed later. With the larger full bearing trees that Stassen (1987) studied, pruning accounted for the loss of 1.80 g of nitrogen per kg fruit produced. In the current study, the nitrogen loss due to pruning equates to 0.20 g of nitrogen per kg fruit produced. The difference of 1.6 g of nitrogen per kg fruit produced accounts for 89.89% of the difference between the requirement determined in the current trial and the findings by Stassen in 1987. This is due to the fact that the modern central leader trees are smaller and carry much less structural wood than the traditional large open vase trees with multiple leaders such as those studied by Stassen (1987).

The annual amount of phosphorous required to produce one ton of fruit was found to be 0.35kg. This is close to the 0.4g of phosphorous to produce 1kg of fruit that Stassen (1987) found, as well as the 0.5kg of phosphorous to produce one ton of fruit that Stassen (2001) proposed later. Stassen *et al.* (1983) proposed that by applying enough phosphorous ($30mg.kg^{-1}$) during soil preparation, P can be supplied for the whole commercial lifetime of the tree, as phosphorus is not lost through leaching.

This proposal is supported by the data since the P requirement determined during the trial was much the same as the findings by Stassen (1987).

The annual amount of potassium required to produce one ton of fruit was found to be 4.43kg. This is higher than, but still compares well to 3.2g of potassium to produce 1kg of fruit that Stassen (1987) found. It is, however, closer to the 3.5kg of potassium to produce one ton of fruit that Stassen (2001) proposed.

The annual amount of calcium required to produce one ton of fruit was found to be 1.53kg. This is lower than the 3.0 of calcium to produce 1kg of fruit that Stassen proposed in 1987 and in 2001. With the larger full bearing trees that Stassen (1987) studied, pruning accounted for the loss of 1.3 g of calcium per kg fruit produced. In the current study, the calcium loss due to pruning equates to 0.20 g of calcium per kg fruit produced. The difference of 1.1 g of calcium per kg fruit produced accounts for 74.83% of the difference between the requirement determined in the current trial and the findings by Stassen (1987). As in the case of nitrogen, this is due to the fact that the modern central leader trees are smaller, and much less of the total dry mass is structural wood, than the traditional large open vase trees studied by Stassen (1987). Stassen *et al.* (1983) proposes the correction of soil calcium content during soil preparation, as in the case of phosphorous, after which maintenance liming practices must be employed to counteract waste, leaching and acidification. This principal is supported by the data since the Ca requirement determined during the trial was lower than that found by Stassen (1987).

Stassen (1987) found that young peach trees and full-bearing peach trees require respectively 2.8g and 0.7g of magnesium annually to produce 1kg of fruit. At a later stage Stassen (2001) estimated that 0.7 kg magnesium is required to produce one ton of fruit. Results of the current trial indicate a Mg requirement of 0.52 kg Mg per ton of fruit per hectare. This is only slightly lower than the requirement proposed by Stassen in 1987 and in 2001 for full bearing peach trees.

Sodium is not commonly considered an essential micro-element and previous work on the sodium requirement of peaches and nectarines could not be found. Data from this

trial suggested 32.45 g Na per hectare was taken up by the nectarine trees for every ton of fruit produced.

The annual amount of manganese required to produce one ton of fruit was found to be 9.44g. This is close to, but higher than, the 6.0g of manganese to produce one ton of fruit that Stassen proposed in 2001.

The annual iron requirement to produce one ton of fruit was determined as 37.46g. This is higher than, but close to the 28g of iron to produce one ton of fruit that Stassen proposed in 2001.

Current results indicate a requirement of 3.24g Cu per ton of fruit per hectare. This is higher than to the 1.0g of copper to produce one ton of fruit that Stassen proposed in 2001.

The annual amount of zinc required to produce one ton of fruit was found to be 13.95g. This is higher than the 8.0g of Zn required per ton of fruit that Stassen proposed in 2001.

The annual amount of boron required to produce one ton of fruit was found to be 10.52g. This is slightly higher, but still compares well to the 8.0g of boron to produce one ton of fruit that Stassen proposed in 2001.

## 4.5. Conclusion

The guidelines (table 1a and 1b) found for the mineral nutrition of full bearing higher density nectarine orchards compares well to previously published work. While these guidelines can be very valuable in compiling mineral nutrition program for nectarine orchards, it is important to remember that orchard characteristics and cultural practices play an important role in the recycling of nutrients in the orchard. A portion of the nutrients that is lost during leaf fall or as a part of prunings can be recycled back to the soil via the process of mineralization (Stassen and North, 2005).

In orchards where efforts are made to retain the prunings or fallen leaves or where additional organic matter such as wood chips or straw is utilized as mulch or compost, one can expect that nutrients, in time, will become available for uptake by the tree. In such cases the nutritional requirement guidelines given can be adjusted downwards according to the performance of the orchard and with the help of leaf and soil analysis. Where additional organic matter is applied, this material must be analyzed and the analysis must be considered during nutritional recommendations. Upward adjustments of these guidelines may also be necessary in certain situations where nutrients may be removed from the system by leaching. Other scenarios, for instance very poor soil fertility or a less effective irrigation system, may also warrant upward adjustments of the guidelines. This should also be done according to the performance of the orchard and with the help of leaf and soil analysis.

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**Tables**

**Table 1:** Guidelines for the requirement of macro-elements in kg and micro-elements in g by higher density full bearing nectarine trees (cv. Donnarine) to produce one ton of fruit.

a.) Macro-elements

| **Tree part** | **Macro-elements (kg)** | | | | |
|---|---|---|---|---|---|
| | **N** | **P** | **K** | **Ca** | **Mg** |
| Fruit | 1.84 | 0.24 | 3.23 | 0.09 | 0.14 |
| Leaves | 1.56 | 0.05 | 1.00 | 1.19 | 0.35 |
| 1st Summer Pruning | 0.07 | 0.01 | 0.07 | 0.06 | 0.01 |
| 2nd Summer Pruning | 0.06 | 0.01 | 0.05 | 0.08 | 0.01 |
| Winter Pruning | 0.07 | 0.01 | 0.03 | 0.06 | 0.01 |
| Fixation | 0.21 | 0.02 | 0.05 | 0.05 | 0.01 |
| Total | 3.82 | 0.35 | 4.43 | 1.53 | 0.52 |

b.) Micro-elements

| **Tree part** | **Micro-elements (g)** | | | | | |
|---|---|---|---|---|---|---|
| | **Na** | **Mn** | **Fe** | **Cu** | **Zn** | **B** |
| Fruit | 16.64 | 2.16 | 9.15 | 0.58 | 2.16 | 7.69 |
| Leaves | 10.69 | 6.70 | 24.83 | 0.52 | 8.71 | 2.27 |
| 1st Summer Pruning | 0.50 | 0.08 | 0.52 | 0.06 | 0.59 | 0.15 |
| 2nd Summer Pruning | 0.76 | 0.12 | 0.43 | 0.04 | 0.79 | 0.13 |
| Winter Pruning | 1.15 | 0.12 | 0.39 | 1.28 | 0.59 | 0.09 |
| Fixation | 2.71 | 0.25 | 2.12 | 0.77 | 1.12 | 0.20 |
| Total | 32.45 | 9.44 | 37.46 | 3.24 | 13.95 | 10.52 |

# CHAPTER 5

## The influence of pre-harvest nutrient solution electrical conductivity (EC) on fruit quality of 'Donnarine' nectarines under pulsating drip fertigation.

### 5.1. Introduction

In his preface of the book "Integrated view of Fruit and Vegetable Quality" Florkowski (2000) states that no single attempt at defining fruit quality has ever found unequivocal support. This may be the reason why Shewfelt (1999) states that the term quality is frequently used in post harvest studies, but rarely defined. The ultimate objective of the production, handling and distribution of fresh fruits and vegetables is to satisfy customers and quality is related to customer satisfaction (Shewfelt, 1999). While fruit size and colour has always been important, in the last decade taste, aroma and food safety as fruit quality parameters have grown in importance in American and European markets. The degree of liking and consumer acceptance was found to be associated with ripe soluble solids concentration (RSSC) regardless of ripe titratable acidity (RTA) (Crisosto and Crisosto, 2005). Consumers find peaches and nectarines with 11% SSC or higher highly acceptable (Claypool, 1977).

Over the years, in the ongoing pursuit of consumer satisfaction, many pre-harvest cultural practices have been employed to manipulate fruit and vegetable quality. Crisosto *et al.* (1997) reviewed orchard factors affecting postharvest stone fruit quality. These factors include irrigation, the use of girdling, manipulation of crop load, fruit canopy position as well as mineral –and foliar nutrition (Crisosto *et al.*, 1997). A practice, widely used in the vegetable industry due to positive effects on fruit quality, is the manipulation of the electrical conductivity (EC) of the nutrient solution supplied to the plants. Many authors have shown that an increase in the pre-harvest nutrient solution EC results in an increase in the total soluble solids (TSS) content of a variety of fruit types. Auerswald *et al.* (1999) demonstrated that an increase in nutrient solution EC resulted in an increase in the reducing sugar content and titratable acidity (TA), subsequently influencing the intensity of several sensory attributes of tomatoes. Of all crops, tomatoes probably enjoy the highest amount of EC related publications as reviewed by Caurtero and Rafael (1999). Janse (1989)

improved sweet pepper flavour by increasing the nutrient solution EC and Chartzoulakis (1995) demonstrated an increase in TSS of cucumbers with an increase in salinity. Salinity and nutrient solution concentration trials were also conducted on muskmelons (Combrink *et al.*, 1995), egg plants (Chartzoulakis, 1995), celery (Pardossi *et al.*, 1999) and lettuce (Serio *et al.*, 2001).

Producers who make use of the pulsating drip fertigation system for fruit production have the capabilities to manage, manipulate and monitor the EC of the nutrient solution delivered via the drip system to the fruit trees. With the emergence of this system in the fruit industry and the simultaneous market trends towards fruit with better taste and aroma (flavour), it was inevitable that the effects of an increase in nutrient solution EC on fruit quality would be studied. Besset *et al.* (2001) showed that water stress during the final stage of rapid fruit growth could result in an improvement in peach taste. In this trial the effect of four different nutrient solution EC levels applied to nectarine trees for three periods of different length during the final stage of rapid fruit growth were studied over two seasons. The aim was to determine whether raising the EC of the nutrient solution supplied to the trees for a certain period before harvest would result in an increase in TSS.

## 5.2. Materials and methods:

### 5.2.1. Location

A commercial ‘Donnarine’ nectarine orchard planted in July 2000 near Prince Alfred Hamlet, South Africa (33º21’S. 19º18’E) was used for the trial. The trees are planted in a North-South row direction with a planting density of 4.5 X 1.5 meters and pruned and trained to the central leader system. The orchard is ridged and a straw mulch was applied.

### 5.2.2. Treatments

The treatments used in the trial are explained in table 1. Six 5 000 liter tanks and a pump was connected to Netafim™ RAM™ integral pressure compensated dripper lines (2.3 litre per hour drippers spaced at 50 centimetres) in such a way that, through usage of dripper ring clips, any tree in the experimental rows could be irrigated from any of the six tanks shown in figure 1. This design allowed full adaptability of the system to the statistical design of the experiment. The nutrient solution used was the Omnia Nutrigro/Nutriplex formulation at the amounts required to achieve the desired EC levels. Normally nutrient solution EC levels are maintained between 0.5 $mS.cm^{-1}$ and 1 $mS.cm^{-1}$. Each tree received 20.7 liters of the nutrient solution each day divided into in three, one hour long, pulses of 6.9 liters per tree. By increasing the EC of the nutrient solution, one also increased the amount of nutrients delivered to the trees. The amount of nutrients delivered to the trees for the different EC treatment levels are given in table 2a and b.

### 5.2.3. Statistical design and analysis

The trial design was a factorial, with four nutrient solutions of different EC applied over three durations. The experimental design was a randomised complete block with three blocks. Each block consisted of 60 trees in the same row with five trees per experimental unit. In order to exclude any overlapping effect from neighbouring treatments in the same row, tree one and trees four and five in each experimental unit were not used for measurement. As found during soil trench investigations, the high ridges in the orchard excluded effects between rows and each row represented a separate block in the statistical design.

Statistical analysis of the data was performed using the SAS Enterprise Guide statistical software program. Analysis of variance (ANOVA), LSD T-tests, contrasts (F-tests) and covariant analysis was used for data analysis.

### 5.2.4. Measurements

Internal fruit quality at harvest was studied through measurements of fruit firmness, total soluble solids (TSS), titratable acidity (TA), TSS to TA ratio for both seasons. Internal fruit quality after cold storage was also assessed through the same measurements. Thirty fruit per experimental unit of the same visual maturity and size were sampled during the first pick of the 2003 harvest and the second pick of the 2004 harvest. Fifteen of the sampled fruit were analysed at harvest and fifteen more went into cold storage for a period of 25 days at -0.5°C and 3 days at 15°C. The percentage fruit weight lost during storage was determined.

The fruit analysis at harvest and after cold storage consisted of measurements of fruit diameter, fruit weight and fruit firmness with a fruit texture analyser (FTA). Fruit firmness was determined with an 11mm penetrometer tip. All fruit from each experimental unit with the exception of fruit with a firmness value between 4.5 and 14 kg were juiced together. The juice was used to determine the total soluble solids content (TSS) of the fruit with an electronic refractometer. The titratable acidity was determined by means of titration with sodium hydroxide. From this data the total soluble solids to titratable acidity (TSS/TA) ratio was calculated.

## 5.3. Results

### 5.3.1. Fruit quality at harvest

The data from fruit quality assessments done at harvest for the 2003 and 2004 seasons is presented in table 3. At harvest in 2003, the measured TSS of fruit from trees receiving a nutrient solution with an EC of 2.33 $mS.cm^{-1}$ was lower than the TSS from fruit receiving nutrient solutions with EC's of 1.00 $mS.cm^{-1}$ and 1.67 $mS.cm^{-1}$ at a significance level of 5.71% (Pr>F=0.0571).

EC levels had a significant negative linear relationship (Pr>F=0.0284) with the total soluble solids content of fruit at harvest in 2003. This relationship is shown in figure 2. The TSS:TA ratio is commonly used as an indication of fruit taste. Figure 3 shows

that the TSS:TA ratio had a significant quadratic relationship (Pr>F=0.0326) with the treatment duration (DBH). This relationship was especially evident with nutrient solution EC levels of 1.00 $mS.cm^{-1}$, 1.67 $mS.cm^{-1}$ and 3.00 $mS.cm^{-1}$. The trends found in TSS content of fruit in 2003 were not repeated in 2004. However, a very similar quadratic relationship as in 2003 between the TSS to TA ratio and the treatment duration (figure 4) existed in 2004 (Pr>F=0.0705), but the significance was less at 7.05%.

### 5.3.2. Fruit quality after cold storage

The data from fruit quality assessments done at harvest for the 2003 and 2004 seasons is presented in table 4. The differences and trends found at harvest were not evident after cold storage. This is probably an effect of ongoing post harvest metabolic processes in the fruit during cold storage. Differences in titratable acidity (Pr>F=0.1080) after cold storage for the 2004 season were not significant.

During cold storage after the 2004 season fruit from trees receiving treatments from 10 days before harvest lost more weight than fruit from trees receiving treatments from 5 days before harvest (Pr>F=0.0685), but these differences were only significant at a 6.85% significance level. These differences were due to a quadratic treatment duration effect, illustrated in figure 5, at a significance level of 8.22% (Pr>F=0.0822).

## 5.4. Discussion

Increasing the EC of the nutrient solution applied to the nectarine trees for certain periods before harvest did not result in an increase in total soluble solids. At harvest, during the 2003 season, the opposite was true where an increase in EC had a significant negative linear relationship with the soluble solids content of the fruit.

The only trend that was found in both seasons was the similar quadratic relationships between the TSS to TA ratio and the treatment duration for fruit analyzed at harvest. This indicates that pre-harvest cultural practices applied around 10 or 11 days before harvest can have an effect on the TSS to TA ratio of the fruit. All TSS levels measured during the trial were above the soluble solids content of 11% as proposed

by Claypool (1977) for consumer acceptability. This was due to the application of good pre-harvest practices such as those reviewed by Crisosto *et al.* (1997). These included good crop thinning, effective light management through summer pruning and accurate amounts and timing of mineral –and foliar nutrition.

## 5.5. Conclusion

Raising the nutrient solution EC to positively affect fruit quality is a technique widely utilised in the vegetable industry. This technique did, however, not have similar positive effects on nectarine fruit grown under a pulsating drip fertigation system. Good production practices resulted in all fruit assessed during the trial having acceptably high TSS values. The lowest TSS value of all fruit analysed was 13.01 ºBrix. This value is still higher than the soluble solids content of 11% as proposed by Claypool (1977) for consumer acceptability. Crisosto *et al.* (1997) reviewed the effects of orchard cultural practices on the postharvest quality of stone fruit. These cultural practices should be the primary focus of producers who wish to alter or improve the postharvest quality of their crop.

## 5.6. Literature cited

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## Tables

**Table 1:** The treatment combinations applied in the 2003 and 2004 seasons.

| Treatment | Nutrient solution EC ($mS.cm^{-1}$) | | Duration of application (Days before harvest) | |
|---|---|---|---|---|
| | 2003 | 2004 | 2003 | 2004 |
| 1 | 1.00 | 0.50 | 16 | 15 |
| 2 | 1.00 | 0.50 | 11 | 10 |
| 3 | 1.00 | 0.50 | 6 | 5 |
| 4 | 1.67 | 1.50 | 16 | 15 |
| 5 | 1.67 | 1.50 | 11 | 10 |
| 6 | 1.67 | 1.50 | 6 | 5 |
| 7 | 2.33 | 2.50 | 16 | 15 |
| 8 | 2.33 | 2.50 | 11 | 10 |
| 9 | 2.33 | 2.50 | 6 | 5 |
| 10 | 3.00 | 3.50 | 16 | 15 |
| 11 | 3.00 | 3.50 | 11 | 10 |
| 12 | 3.00 | 3.50 | 6 | 5 |

**Table 2:** The amount of macro-nutrients (kg/ha/day) and micronutrients (g/ha/day) applied for all EC levels.

a.

| Season | EC | Macro-Nutrients (kg/ha/day) | | | | | |
|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | S |
| 2003 | 1.00 | 2.94 | 0.69 | 3.74 | 2.36 | 0.66 | 1.17 |
| | 1.67 | 4.90 | 1.15 | 6.23 | 3.93 | 1.10 | 1.94 |
| | 2.33 | 6.87 | 1.61 | 8.72 | 5.51 | 1.54 | 2.72 |
| | 3.00 | 8.83 | 2.07 | 11.22 | 7.08 | 1.98 | 3.50 |
| 2004 | 0.50 | 1.68 | 0.39 | 2.13 | 1.35 | 0.38 | 0.66 |
| | 1.50 | 4.55 | 1.07 | 5.78 | 3.65 | 1.02 | 1.80 |
| | 2.50 | 7.41 | 1.74 | 9.42 | 5.95 | 1.66 | 2.93 |
| | 3.50 | 10.29 | 2.41 | 13.07 | 8.25 | 2.30 | 4.07 |

b.

| Season | EC | Micro-Nutrients (g/ha/day) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Fe | Zn | Mn | B | Cu | Mo |
| 2003 | 1.00 | 33.73 | 4.60 | 7.67 | 9.20 | 1.53 | 1.53 |
| | 1.67 | 56.20 | 7.66 | 12.77 | 15.33 | 2.55 | 2.55 |
| | 2.33 | 78.67 | 10.73 | 17.88 | 21.45 | 3.58 | 3.58 |
| | 3.00 | 101.20 | 13.80 | 23.00 | 27.60 | 4.60 | 4.60 |
| 2004 | 0.50 | 19.23 | 2.62 | 4.37 | 5.24 | 0.87 | 0.87 |
| | 1.50 | 52.08 | 7.10 | 11.84 | 14.20 | 2.37 | 2.37 |
| | 2.50 | 84.94 | 11.58 | 19.30 | 23.17 | 3.86 | 3.86 |
| | 3.50 | 117.86 | 16.07 | 26.79 | 32.14 | 5.36 | 5.36 |

**Table 3:** The fruit firmness, total soluble solids (TSS), titratable acidity (TA) and TSS to TA ratio for 'Donnarine' nectarine fruit at harvest for 2003 and 2004.

| Treatment | Firmness (kg) | TSS (°Brix) | TA (%) | TSS:TA |
|---|---|---|---|---|
| **2003 At Harvest** | | | | |
| **EC ($mS.cm^{-1}$)** | | | | |
| 1.00 | 9.36 A | 14.23 A | 0.94 A | 15.17 A |
| 1.67 | 10.04 A | 14.44 A | 0.95 A | 15.27 A |
| 2.33 | 9.81 A | 13.01 B | 0.87 A | 14.96 A |
| 3.00 | 9.87 A | 13.26 AB | 0.88 A | 15.08 A |
| LSD | 0.9988 | 1.2175 | 0.0908 | 0.8183 |
| **Duration (Days before harvest)** | | | | |
| 6 | 9.34 A | 14.23 A | 0.95 A | 14.99 AB |
| 11 | 9.95 A | 13.48 A | 0.87 B | 15.57 A |
| 16 | 10.02 A | 13.50 A | 0.91 AB | 14.79 B |
| LSD | 0.8650 | 1.0544 | 0.0786 | 0.7086 |
| **Significance** | | | | |
| EC | 0.5385 | 0.0571 | 0.2151 | 0.8782 |
| Duration | 0.2264 | 0.2594 | 0.1114 | 0.0843 |
| EC*Duration | 0.5184 | 0.4713 | 0.7068 | 0.6944 |
| **2004 At Harvest** | | | | |
| **EC ($mS.cm^{-1}$)** | | | | |
| 0.5 | 9.73 A | 15.18 A | 1.55 A | 9.79 A |
| 1.5 | 8.83 A | 14.19 A | 1.47 A | 9.71 A |
| 2.5 | 10.37 A | 14.66 A | 1.55 A | 9.42 A |
| 3.5 | 10.24 A | 14.66 A | 1.50 A | 9.73 A |
| LSD | 1.6095 | 1.1724 | 0.105 | 0.614 |
| **Duration (DBH)** | | | | |
| 5 | 10.01 A | 14.34 A | 1.52 A | 9.46 A |
| 10 | 9.68 A | 14.75 A | 1.48 A | 9.94 A |
| 15 | 9.68 A | 14.92 A | 1.55 A | 9.59 A |
| LSD | 1.3938 | 1.0153 | 0.0909 | 0.5317 |
| **Significance** | | | | |
| EC | 0.2139 | 0.4021 | 0.3014 | 0.6181 |
| Duration | 0.8522 | 0.4931 | 0.3076 | 0.1681 |
| EC*Duration | 0.6721 | 0.9669 | 0.6608 | 0.9798 |

**Table 4:** The percentage weight lost during storage, fruit firmness, total soluble solids (TSS), titratable acidity (TA) and TSS to TA ratio for 'Donnarine' nectarine fruit after cold storage for 2003 and 2004.

| Treatment | Percentage weight lost (%) | Firmness (kg) | TSS (°Brix) | TA (%) | TSS:TA |
|---|---|---|---|---|---|
| **2003 After cold storage** | | | | | |
| **EC ($mS.cm^{-1}$)** | | | | | |
| 1 | 8.58 A | 1.49 A | 15.16 A | 0.78 A | 21.04 A |
| 1.67 | 7.02 A | 1.72 A | 14.97 A | 0.64 A | 26.08 A |
| 2.33 | 7.48 A | 1.82 A | 15.21 A | 0.65 A | 25.67 A |
| 3 | 6.2 A | 1.79 A | 14.68 A | 0.62 A | 24.46 A |
| LSD | 2.3794 | 0.3529 | 1.6693 | 0.2027 | 5.7857 |
| **Duration (Days before harvest)** | | | | | |
| 6 | 6.17 A | 1.57 A | 14.94 A | 0.67 A | 23.34 A |
| 11 | 7.63 A | 1.74 A | 15.25 A | 0.69 A | 24.91 A |
| 16 | 8.08 A | 1.83 A | 14.83 A | 0.65 A | 24.99 A |
| LSD | 2.0597 | 0.3055 | 1.445 | 0.1754 | 5.0083 |
| **Significance** | | | | | |
| EC | 0.2553 | 0.3224 | 0.9221 | 0.4685 | 0.3145 |
| Duration | 0.1362 | 0.1989 | 0.8841 | 0.9006 | 0.7681 |
| EC*Duration | 0.4034 | 0.0705 | 0.6765 | 0.0898 | 0.029 |
| **2004 After cold storage** | | | | | |
| **EC ($mS.cm^{-1}$)** | | | | | |
| 0.5 | 14.74 A | 1.46 A | 16.13 A | 1.21 AB | 13.43 A |
| 1.5 | 14.41 A | 1.47 A | 16.22 A | 1.18 B | 13.82 A |
| 2.5 | 16.05 A | 1.51 A | 16.83 A | 1.28 A | 13.21 A |
| 3.5 | 14.61 A | 1.42 A | 16.68 A | 1.2 AB | 13.86 A |
| LSD | 3.3899 | 0.2657 | 0.9167 | 0.0815 | 0.8742 |
| **Duration (Days before harvest)** | | | | | |
| 5 | 16.87 A | 1.46 A | 16.35 A | 1.23 A | 13.32 A |
| 10 | 13.46 B | 1.4 A | 16.33 A | 1.19 A | 13.79 A |
| 15 | 14.52 AB | 1.53 A | 16.72 A | 1.23 A | 13.64 A |
| LSD | 2.9358 | 0.2301 | 0.7939 | 0.0706 | 0.7571 |
| **Significance** | | | | | |
| EC | 0.746 | 0.9156 | 0.3351 | 0.108 | 0.3662 |
| Duration | 0.0685 | 0.5045 | 0.5364 | 0.3125 | 0.4305 |
| EC*Duration | 0.8604 | 0.0709 | 0.1875 | 0.1868 | 0.2746 |

**Figures**

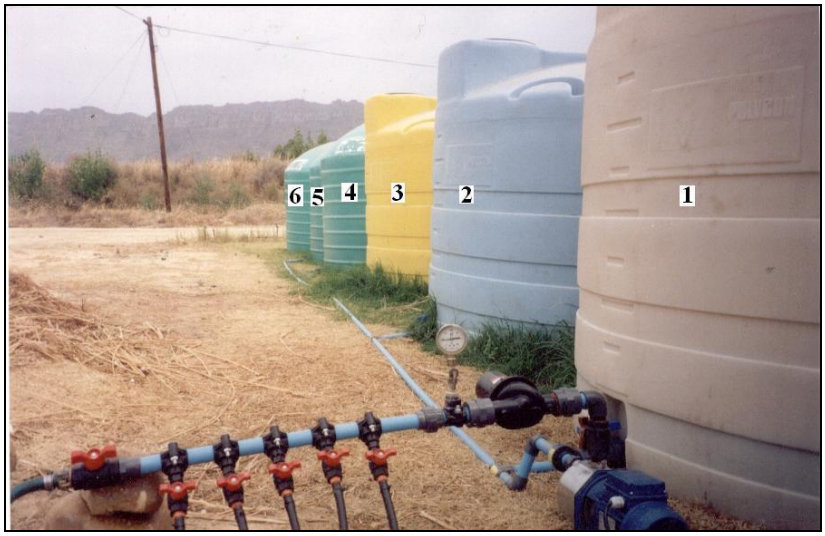


**Figure 1:** The water and nutrient tanks as set up and in the trial. Tank 1: 1.0 (2003) or 0.5 (2004) $mS.cm^{-1}$ nutrient solution. Tank 2: 1.6 (2003) or 1.5 (2004) $mS.cm^{-1}$ nutrient solution. Tank 3: 2.3 (2003) or 2.5 (2004) $mS.cm^{-1}$ nutrient solution. Tank 4: 3.0 (2003) or 3.5 (2004) $mS.cm^{-1}$ nutrient solution. Tank 5: Water tank used to flush the pump and filter between treatments. Tank 6: Spare tank in case of unforeseen events.

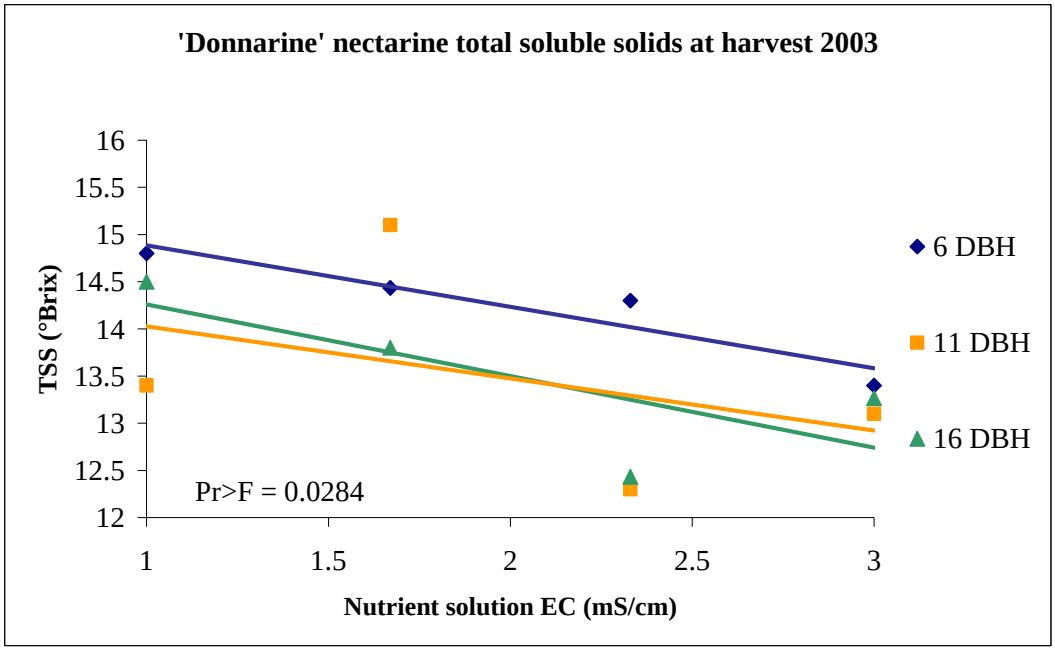


**Figure 2:** The negative linear relationship between totals soluble solids content (TSS) of fruit at harvest in 2003 and the nutrient solution EC for 3 treatment durations.

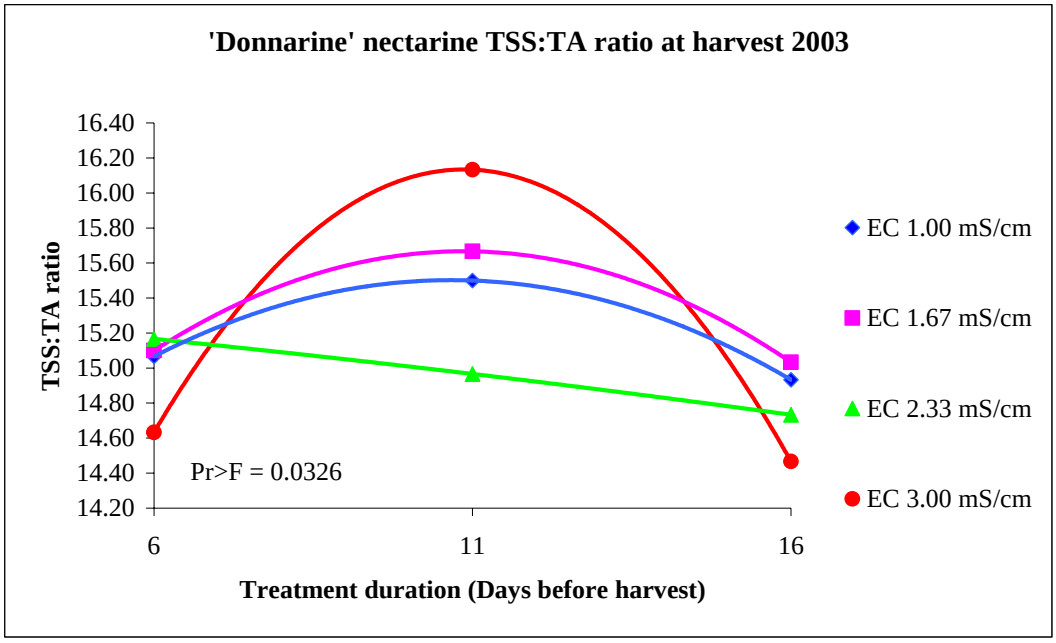


**Figure 3:** The quadratic relationship between the TSS to TA ratio and the treatment duration found at harvest in 2003 for 4 EC levels.

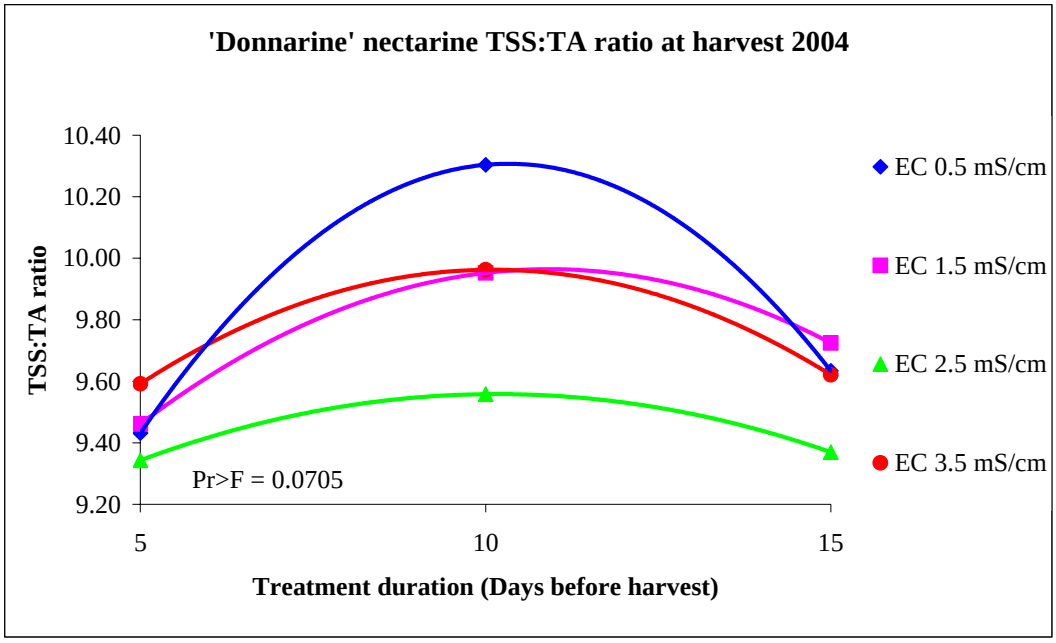


**Figure 4:** The quadratic relationship between the TSS to TA ratio and the treatment duration found at harvest in 2004 for 4 EC levels.

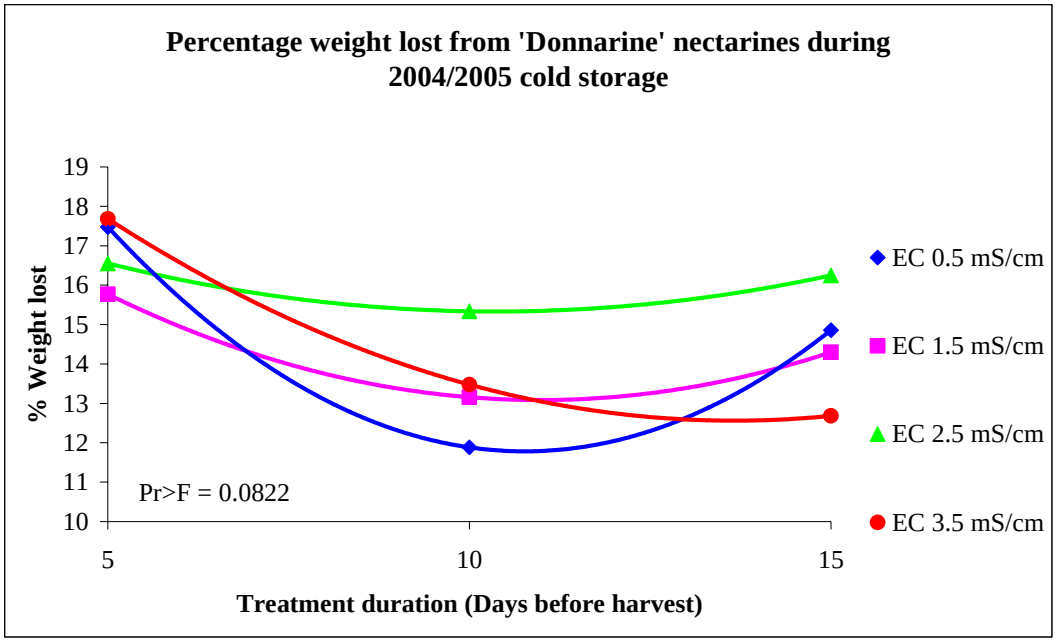


**Figure 5:** The quadratic relationship between the percentage fruit weight lost during 2004/2005 cold storage and the treatment duration for 4 EC levels.

## GENERAL DISCUSSION

Inadequate or wrong mineral nutrition practices will have a negative impact on the potential income of an orchard as it directly influences the growth and development of the tree as well as other aspects like internal fruit quality and fruit size. The correct and accurate mineral nutrition of nectarine trees are, therefore, of vital importance to the modern fruit producer.

Previous research into the uptake, distribution and requirement of mineral nutrients by peach trees mostly made use of old style orchards, or trees grown in sand culture and concentrated on the essential macro nutrients only. The uptake, distribution and reserve role of micro nutrients in peach and nectarine trees was not studied. Modern nectarine orchards are planted at higher densities and the trees differ in architecture when compared to old style orchards. In addition, many modern-day producers make use of sophisticated water and nutrient management strategies such as ‘daily drip fertigation’ or ‘open hydroponic systems’ in their orchards. The justified a reevaluation of the uptake and distribution patterns of mineral nutrients, including micro nutrients, by nectarine trees.

The study of macro-element uptake and distribution by full bearing ‘Donnarine’ nectarine trees (chapter 2) confirmed the importance of nitrogen and phosphorous as reserves in the tree. 41.5% of nitrogen and 35% of phosphorous manifested in the new growth (fruit, leaves and developing shoots) from winter up to pip hardening originated from reserves in the permanent structure (roots, scaffold branches, stem and bark). If deficiencies of these elements are found, it should be corrected during the post harvest period.

This study confirmed previous findings that calcium does not have an important reserve role in the tree with only 2.9% of calcium present in the new growth at pip hardening representing reserves translocated from the permanent structures. Calcium uptake from the onset of the growing season, is therefore important.

Contrary to previous findings, of the magnesium and potassium present in the new growth at pip hardening, only 3% and 2.1% respectively, originated from reserves in the permanent structure of the tree. This suggests that that the uptake of these nutrients may be more demand driven than previously thought. These elements must be available for uptake from the onset of the growing season.

Current findings support previous suggestions that potassium uptake appears to be proportional to vegetative growth as 59.2% of potassium taken up during the first portion of the growing season (winter to pip hardening), was translocated to the leaves. From pip hardening to harvest, coinciding with the cell enlargement phase of stone fruit growth, 94.2% of potassium uptake was translocated to the fruit. This underlines the important osmotic role potassium fulfils during cell enlargement.

Results of the study on micro-element uptake and distribution by the same ‘Donnarine’ nectarine trees (chapter 3) showed that manganese and iron and, to a lesser extent, zinc and boron, have reserve roles in nectarine trees. 46.2% of manganese and 59.5% of iron present in the new at pip hardening originated from reserves in the permanent structure. The values for zinc and boron are 10.5% and 4.9% respectively. This implies that the tree should contain adequate reserves of these elements at the start of the growing season. If deficiencies in the above mentioned elements, especially Fe and Mn, are prevalent, it must be taken into account during the compilation of mineral nutrition program.

According previous findings no Fe, Mn and Zn, and approximately 33% of B, is translocated back to the permanent structure of the tree before leaf drop. These findings are, however, based primarily on apple research. This indicates that, of the above mentioned elements, only B deficiency can in theory be effectively treated through post harvest foliar sprays. Future research should focus on quantifying how much nutrients, especially the micro-nutrients Fe, Mn and Zn, are lost through leaf fall in nectarines. This will enable further fine tuning of mineral nutrition programs for nectarines orchards.

Nutrient losses through fruit, leaves and pruning, as well as fixation in the permanent structure, were calculated and related to the requirement per hectare to produce one ton of nectarines. This information was used to produce guidelines regarding the nutritional requirements of modern higher density nectarine orchards. These guidelines are respectively 3.82kg N, 0.35kg P, 4.43kg K, 1.53kg Ca, 0.52kg Mg, 32.45g Na, 9.44g Mn, 37.46g Fe, 3.24g Cu, 13.95g Zn and 10.52g B per ton of fruit produced. These guidelines compare well with previously published work and differences can largely be attributed to changes in tree architecture. Modern higher density nectarines trees have less structural wood, thus loosing fewer nutrients trough winter pruning. This is discussed in more detail in chapter 4.

While these guidelines can be very valuable in compiling mineral nutrition program for nectarine orchards, it is important to use them in context. Orchard characteristics and cultural practices play an important role in the recycling of nutrients in the orchard and no two orchards are exactly the same. In orchards where efforts are made to retain the prunings or fallen leaves, or where additional organic matter such as wood chips or straw is utilized as mulch or compost, one can expect that nutrients, in time, will become available for uptake by the tree. In such cases the nutritional requirement guidelines given can be adjusted downwards according to the performance of the orchard and with the help of leaf and soil analysis. Upward adjustments of these guidelines may also be necessary in certain situations where nutrients may be removed from the system by leaching. Other scenarios, for instance very poor soil fertility or a less effective irrigation system, may also warrant upward adjustments of the guidelines. This should also be done according to the performance of the orchard and with the help of leaf and soil analysis.

A separate study focused on the influence of the pre-harvest nutrient solution's electrical conductivity (EC) on fruit quality of 'Donnarine' nectarines under pulsating drip fertigation (chapter 5). Previous studies have shown that water stress during the final stage of rapid fruit growth could result in an improvement in peach total soluble solids (TSS). The use of a 'pulsating daily drip fertigation system' enables the grower to raise the nutrient solution's EC prior to harvest in an attempt to induce a similar osmotic stress

on the tree. In the trial this practise did not have positive effects on nectarine fruit quality. Correct and timely cultural practices such as accurate nutrition, light management, crop load management, vigour control, correct water management, etc. should be the primary focus of producers who wish to improve the internal quality of their fruit.